

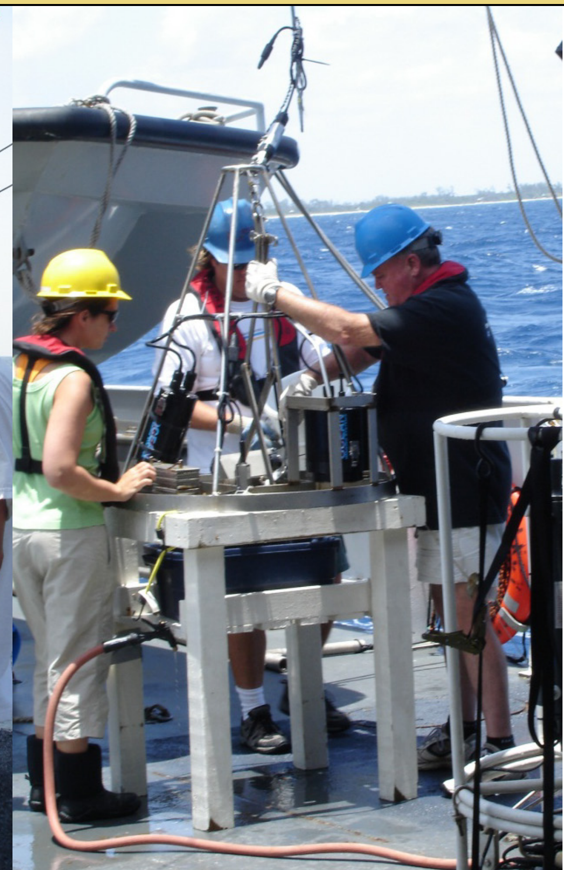

Ecological Condition of Coastal Ocean Waters of the U.S. Continental Shelf off South Florida: 2007

NOAA Technical Memorandum NOS NCCOS 159
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U.S. Department of Commerce
National Oceanic and
Atmospheric Administration
National Ocean Service
Silver Spring, MD 20910

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Preface

This document provides an assessment of ecological condition, with an emphasis on soft-bottom habitats, in coastal ocean waters of the U.S. continental shelf off south Florida, from Anclote Key on the Gulf coast to West Palm Beach on the Atlantic coast, inclusive of the Florida Keys National Marine Sanctuary. Sampling was conducted in May 2007. The project was a large collaborative effort by the National Oceanic and Atmospheric Administration (NOAA)/National Centers for Coastal Ocean Science (NCCOS), U.S. Environmental Protection Agency (EPA), U.S. Geological Survey (USGS), Florida Keys National Marine Sanctuary (FKNMS), NOAA/Oceanic and Atmospheric Research (OAR)/Atlantic Oceanographic and Meteorological Laboratory in Miami, and the Florida Fish and Wildlife Conservation Commission (FWC). This project is part of a series of studies, similar in protocol and design to EPA's Environmental Monitoring and Assessment Program (EMAP) and subsequent National Coastal Assessment (NCA), which extend these prior efforts in estuaries and inland waters out to the coastal shelf, from navigable depths along the shoreline seaward to the shelf break (approximate 100 m depth contour).

The appropriate **citation** for this report is:
Cooksey, C., J. Hyland, M.H. Fulton., E. Wirth, L. Balthis. 2012. Ecological Condition of Coastal Ocean Waters of the U.S. Continental Shelf off South Florida: 2007. NOAA Technical Memorandum NOS NCCOS 159, NOAA National Ocean Service, Charleston, SC 29412-9110. 68 pp.

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Executive Summary

A study was initiated with field work in May 2007 to assess the status of ecological condition and stressor impacts throughout the U.S. Continental Shelf off South Florida, focusing on soft-bottom habitats, and to provide this information as a baseline for evaluating future changes due to natural or human-induced disturbances. The boundaries of the study region extended from Anclote Key on the western coast of Florida to West Palm Beach on the eastern coast of Florida, inclusive of the Florida Keys National Marine Sanctuary (FKNMS), and from navigable depths along the shoreline seaward to the shelf break (~100m). The study incorporated standard methods and indicators applied in previous national coastal monitoring programs — U.S. Environmental Protection Agency's (EPA) Environmental Monitoring and Assessment Program (EMAP) and National Coastal Assessment (NCA) — including multiple measures of water quality, sediment quality, and biological condition. Synoptic sampling of the various indicators provided an integrative weight-of-evidence approach to assessing condition at each station and a basis for examining potential associations between presence of stressors and biological responses. A probabilistic sampling design, which included 50 stations distributed randomly throughout the region, was used to provide a basis for estimating the spatial extent of condition relative to the various measured indicators and corresponding assessment endpoints (where available). The study was conducted through a large cooperative effort by National Oceanic and Atmospheric Administration (NOAA)/National Centers for Coastal Ocean Science (NCCOS), EPA, U.S. Geological Survey (USGS), NOAA/Oceanic and Atmospheric Research (OAR)/Atlantic Oceanographic and Meteorological Laboratory in Miami, FKNMS, and the Florida Fish and Wildlife Conservation Commission (FWC).

The majority of the South Florida shelf had high levels of dissolved oxygen (DO) in near-bottom water (> 5 mg L^{-1}) indicative of "good" water quality.. DO levels in bottom waters exceeded this upper threshold at 98.8% throughout the coastal-ocean survey area. Only 1.2% of the region had moderate DO levels (2-5 mg/L) and no part of the survey area had DO <2.0 mg/L. In addition, offshore waters throughout the region had relatively low levels of total suspended solids (TSS), nutrients, and chlorophyll *a* indicative of oligotrophic conditions.

Results suggested good sediment quality as well. Sediments throughout the region, which ranged from sands to intermediate muddy sands, had low levels of total organic carbon (TOC) below bioeffect guidelines for benthic organisms. Chemical contaminants in sediments were also mostly at low, background levels. For example, none of the stations had chemicals in excess of corresponding Effects-Range Median (ERM) probable bioeffect values or more than one chemical in excess of lower-threshold Effects-Range Low (ERL) values. Cadmium was the only chemical that occurred at moderate concentrations between corresponding ERL and ERM values.

Sixty fish samples from 28 stations were collected and analyzed for chemical contaminants. Eleven of these samples (39% of sites) had moderate levels of contaminants, between lower and upper non-cancer human-health thresholds, and ten (36% of sites) had high levels of contaminants above the upper threshold.

A total of 13,477 individual benthic specimens, representing 646 different taxa (391 identified to species level) were collected from the 50 stations (100, 0.04 m^{-2} grab samples sieved at 0.5mm). Densities ranged from 713 to 11,088 m^{-2} and averaged 4,335 m^{-2} across the survey area and there were no samples that were totally devoid of benthic fauna. Species richness ranged from 15 to 89 taxa $grab^{-1}$ and averaged 45 taxa $grab^{-1}$, while H′ diversity (log base 2) ranged from 1.36 to 7.1 $grab^{-1}$ and averaged 5.4 $grab^{-1}$. Numbers of taxa found in these samples were relatively high compared to other shelf regions along the Atlantic coast.

Polychaetes were the dominant taxa, both by percent abundance (59%) and percent taxa (54%), followed by crustaceans. Collectively, these two groups represented 76% of both the total faunal abundance and number of taxa. The 10 most abundant taxa included the polychaetes *Prionospio cristata*, *Goniadides carolinae*, *Fabricinuda trilobata*, *Armandia maculata*, *Chone* spp., *Magelona pettiboneae, Prionospio* spp. and *Paleanotus* spp.; tubificid oligochaetes; and the crustacean *Leptochelia* spp. The tubificids were the most abundant taxon overall with a mean density of 156 m^{-2}, but were closely followed by the polychaete *Prionospio cristata* with a mean density of 151 m^{-2}. The three taxa with the highest frequency of occurrence were the Tubificidae, and the polychaetes *F. trilobata* and *A. maculata*. There were no non-indigenous species identified in any samples collected across the region.

Multi-metric benthic indices are an important tool for detecting pollution-induced signals of a degraded benthos and have been developed for a variety of estuarine applications. However, no such index exists for offshore waters of the south Florida shelf region. In the absence of a benthic index, an alternative approach used here for assessing potential stressor impacts was to look for any linkages between reduced values of biological attributes (lower 10^{th} percentiles of numbers of taxa, diversity, and abundance) and synoptically measured indicators of poor sediment or water quality (defined as DO < 2 mg/L, TOC > 50 mg/g, or ≥ 1 chemical contaminant in excess of ERMs). Because there were no major indications of poor sediment or water quality based on these criteria, there was no evidence of a linkage between degraded environmental conditions and impaired benthic communities. Thus, lower values of key biological attributes appeared to represent parts of a normal reference range controlled by natural factors. Alternatively, it is possible that for some of these offshore sites the lower values of benthic variables reflect symptoms of disturbance induced by other unmeasured stressors, particularly those causing physical disruption of the seafloor (e.g., commercial bottom trawling, cable placement, minerals extraction), which may pose greater risks to offshore living resources and have not been adequately captured. Future monitoring efforts in these offshore areas should include indicators of such alternative sources of disturbance.

Overall, results of this study show that natural resources throughout the South Florida shelf region are in good condition with respect to many of the measured ecological indicators. However, this assessment highlights some areas of concern. For example, there were low but detectable levels of polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) in sediments throughout the region and elevated levels of tissue contaminants in many of the fish examined. It would be prudent to use such information as an early-warning signal and justification for implementing effective coastal management practices in order to prevent potential growth of future environmental risks from increasing human activities in the region. The South Florida continental shelf provides many important ecosystem goods and services across a variety of categories: supporting (e.g., nutrient cycling, reservoirs of biodiversity, habitat for protected species and other natural populations), provisional (e.g., mineral extraction, alternative energy, food, corridors for maritime trade), regulating (e.g., pollutant sequestering, hurricane buffering), and cultural (e.g., swimmable and fishable waters for recreation; protected areas for research, education, and nature conservation). As development continues throughout Florida and the Gulf of Mexico, the coastal-ocean environments should be monitored if we are to better understand and manage these important resources and the functions they provide.

1.0 Introduction

The National Oceanic and Atmospheric Administration (NOAA) and the U.S. Environmental Protection Agency (EPA) both perform a broad range of research and monitoring activities to assess the status and potential effects of human activities on the health of coastal ecosystems and to promote the use of this information in protecting and restoring the Nation's coastal resources. Authority to conduct such work is provided through several legislative mandates including the Clean Water Act (CWA) of 1977 (33 U.S.C. §§ 1251 et seq.), National Coastal Monitoring Act (Title V of the Marine Protection, Research, and Sanctuaries Act, 33 U.S.C. §§ 2801-2805), and the National Marine Sanctuary Act of 2000. Where possible the two agencies have sought to coordinate related activities through partnerships with states and other institutions to prevent duplications of effort and bring together complementary resources to fulfill common research and management goals. Accordingly, in May 2007, NOAA/National Centers for Coastal Ocean Science (NCCOS), EPA, U.S. Geological Survey (USGS), NOAA/Oceanic and Atmospheric Research (OAR)/Atlantic Oceanographic and Meteorological Laboratory in Miami, Florida Keys National Marine Sanctuary (FKNMS), and the Florida Fish and Wildlife Conservation Commission (FWC) combined efforts to conduct a joint survey of ecosystem condition in coastal-ocean (shelf) waters off South Florida using multiple indicators of ecological condition.

The study is part of a series of Regional Ecological Assessments aimed at evaluating condition of living resources and ecosystem stressors throughout coastal-ocean waters of the U.S. The studies are an expansion of EPA's Environmental Monitoring and Assessment Program (EMAP), and subsequent National Coastal Assessment (NCA), which were designed to assess condition of the Nation's environmental resources within a variety of coastal and terrestrial resource categories. The offshore series extends these prior efforts onto the continental shelf, from approximately one nautical mile of the shoreline seaward to the shelf break (~100-m depth contour). Where applicable, sampling has included NOAA's National Marine Sanctuaries (NMS) to provide a basis for comparing conditions in these protected areas to surrounding non-sanctuary waters. To date such surveys have been conducted throughout the western U.S. continental shelf, from the Straits of Juan de Fuca, WA to the U.S./Mexican border (Nelson et al. 2008); shelf waters of the South Atlantic Bight (SAB) from Cape Hatteras, NC to West Palm Beach, FL (Cooksey et al. 2010); shelf waters of the mid-Atlantic Bight (MAB) from Cape Hatteras to Cape Cod, MA (Balthis et al. 2009); the continental shelf along northeastern Gulf of Mexico (Cooksey et al. 2010 cruise report); and the continental shelf along northwestern Gulf of Mexico (Cooksey et al. 2011 cruise report). The current assessment expands this work to coastal-ocean waters (depths of ~10 m -100 m) along the South Florida shelf, from Anclote Key in the Gulf of Mexico to West Palm Beach on the Atlantic coast, inclusive of the Florida Keys National Marine Sanctuary (see Figure 1 below).

The purpose of the present study was to assess the current status of ecological condition and stressor impacts throughout the South Florida shelf and to provide this information as a baseline for evaluating future changes due to natural or human-induced disturbances. To address this objective, the study incorporated standard methods and indicators applied in previous coastal projects including multiple measures of water quality, sediment quality, and biological condition (benthos and fish). Synoptic sampling of the various indicators provided an integrative weight-of-evidence approach to assessing condition at each station and a basis for examining potential associations between presence of stressors and biological responses. Another key feature was the incorporation of a probabilistic sampling design with stations positioned randomly throughout the study area. The probabilistic sampling design provided a basis for making unbiased statistical estimates of the spatial extent of condition relative to the various measured indicators and corresponding thresholds of concern.

The South Florida shelf refers herein to coastal waters along the Florida peninsula from Anclote Key to West Palm Beach and from approximately 1 nautical mile (nm) offshore seaward to the shelf break (100 m). This region contains a diverse array of habitats including calcareous sands, sandy muds, seagrass beds, hardbottom habitats and coral reefs. The geographic feature which most dominates the region is the chain of limestone islands which make up the Florida Keys and which are surrounded by the Florida Keys National Marine Sanctuary (FKNMS). This area is a generally low-energy environment, with intermittent high-energy activity due to tropical storm systems (Hine et al. 2003, Donahue et al. 2008). The South Florida continental shelf is also subject to other extreme natural events and human-related disturbances including harmful algal blooms, coral-bleaching events, ocean acidification, oil spills, and marine debris discharges (Office of National Marine Sanctuaries 2011). Estuaries of south Florida and Florida Bay are also subject to a variety of human-related pressures, including point and non-point source pollution, nutrient enrichment, commercial and recreational fishing, shipping in and out of the Gulf of Mexico, and military operations. The results of this current assessment are of value in broadening our understanding of the status of the region's ecological resources and their controlling factors, including impacts of potential ecosystem stressors.

2.0 Methods

At each station, samples were obtained for characterization of: (1) community structure and composition of benthic macroinfauna (animals retained on a 0.5-mm sieve); (2) concentration of chemical contaminants in sediments (metals, pesticides, PCBs, PAHs, PBDEs); (3) sediment toxicity using Microtox; (4) other general habitat conditions (water depth, dissolved oxygen, conductivity, temperature, chlorophyll *a*, water-column nutrients and total suspended solids, % silt-clay versus sand content of sediment, organic-carbon content of sediment); and (5) condition of targeted demersal fish species (contaminant body burdens and visual evidence of pathological disorders). The following section describes methods used for the collection, processing, and analysis of each of these sample types, which were adopted from the protocols developed for EPA's National Coastal Assessment (USEPA 2001a, 2001b).

2.1 Sampling Design and Field Collections

Sampling was conducted May 15 – May 28, 2007 at 50 stations positioned randomly throughout shelf waters of the South Florida Continental Shelf, from about 1 nautical mile offshore (water depth of ~10 m) seaward to the shelf break (100 m isobath) from West Palm Beach, Florida on the east coast of Florida to Anclote Key, Florida on the west coast of Florida (Figure 1). Ten of the 50 stations were located within FKNMS. The sampling frame for positioning stations was based on a generalized random-tessellation stratified (GRTS) design (Stevens and Olsen 2004). The GRTS design represents a unified strategy for selecting spatially balanced probability samples of natural resources, in which sampling sites are more or less evenly dispersed over the extent of the resource (Stevens and Olsen 2004). Sampling for the survey was conducted on NOAA ship Nancy Foster, Cruise NF-07-08-NCCOS.

Bottom sediments were collected at each station with a $0.04m^2$, Young modified van Veen grab and used for analysis of macroinfaunal communities, concentration of chemical contaminants, % silt-clay, organic-carbon content and toxicity testing (Microtox). A grab sample was deemed successful when the grab unit was >75% full (with no major slumping). Two replicate grab samples were collected for benthic infaunal analysis. Each replicate was sieved onboard through a 0.5-mm screen and preserved in 10% buffered formalin with rose bengal stain. The upper 2-3 cm of sediment from additional multiple grabs (usually at least two) were taken at each station, combined into a single station composite, and then sub-sampled for analysis of metals, organic contaminants (PCBs, pesticides, PAHs), total organic carbon (TOC), and grain size. The grab frame also was equipped with a digital camera, strobe, and bottom-triggered shutter release to capture pictures of the undisturbed ocean floor and any epifaunal species present at the sediment surface just prior to the grab's contact with the bottom.

Both a Seabird 9/11 and Seabird 19 CTD unit, supplied by the NOAA Ship Nancy Foster, were used to acquire continuous profiles of salinity, temperature, pH, dissolved oxygen, and depth during the descent and ascent through the water column. The Seabird 9/11 also was equipped with 12 Nisken bottles to acquire discrete water samples at three designated water depths (near surface, mid-water and near-bottom) for analysis of nutrients, total suspended solids, and chlorophyll.

Hook-and-line fishing methods (up to six fishing rods) were attempted at all 50 stations in an effort to capture demersal fishes for inspection of external pathologies and for subsequent analysis of chemical contaminants in tissues. Terminal tackle consisted of two hooks, 1/0 or 2/0, per line arranged in a setup commonly referred to as a 'porgy rig.' Cut bait, either shrimp or squid, was used. Any captured fish were identified and inspected for gross external pathologies. A total of 60 fish collected among 11 species from 28 of the 50 stations were selected for analysis as follows:

- 2 gray triggerfish (*Balistes capriscus*)
- 2 jolthead porgy (*Calamus bajonado*)
- 1 blackline tilefish (*Caulolatilus cyanops*)
- 26 sandperch (*Diplectrum formosum*)
- 4 red grouper (*Epinephelus morio*)
- 2 bluestriped grunt (*Haemulon sciurus*)
- 9 lane snapper (*Lutjanus synagris*)
- 1 red porgy *(Pagrus pagrus*)
- 6 vermilion snapper (*Rhomboplites aurorubens*)
- 1 saddle bass (*Serranus notospilus*)
- 6 dusky flounder (*Syacium papillosum*)

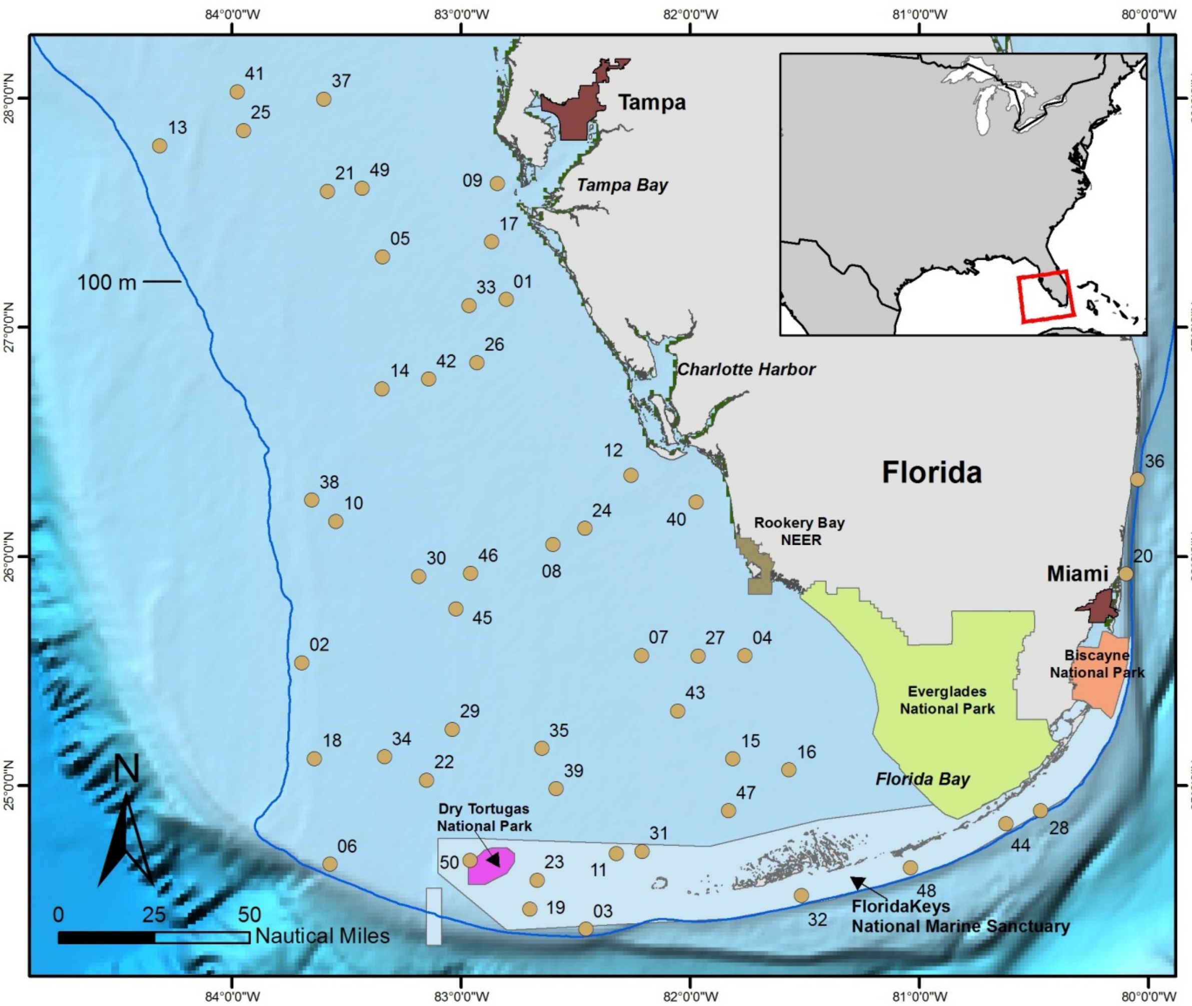

Figure 1. Map of South Florida study area and station locations.

2.2 Water Quality Analysis

Preliminary processing of water samples for nutrients, chlorophyll, and TSS was conducted immediately after collection onboard the research vessel. A portion of the water (~0.5 - 1.0 L) from each station was vacuum-filtered using microfiltration glassware and a GF/F 47mm filter. The filtered water sample was then transferred to a polypropylene bottle, frozen (< -20°C), and analyzed within 30 days for dissolved nutrients including ammonium (NH_{4-} +), nitrate/nitrite ($NO_{2/3}$), orthophosphate (PO_{4-} $^{3-}$), silicate (Si), total dissolved phosphorus (TDP), and total dissolved nitrogen (TDN)). The filter was folded and wrapped in a foil pouch, frozen, and analyzed within 30 days for chlorophyll *a*. An additional sample of water (~0.5 – 1.0 L) was filtered on a pre-weighed GF/F 47mm filter for analysis of total suspended solids (TSS). Whole water samples were frozen in polypropylene bottles and later analyzed for total nitrogen (TN) and total phosphorus (TP). Water chemistry was processed at the Ocean Chemistry Division of NOAA/OAR's Atlantic Oceanographic and Meteorological Laboratory following standard EPA methods (Zhang and Berberian 1997, Zhang and Chi 2002, Zhang et al. 1997a, Zhang et al 1997b).

2.3 Sediment TOC and Grain Size Analysis

Sediment characterization included analyses for TOC and silt-clay content. TOC analysis followed USEPA Method 9060. A minimum of 5g (wet weight) of sediment was initially dried for 48 h. Weighed subsamples were ground to fine consistency and acidified to remove sources of inorganic carbon (e.g., shell fragments). The acidified samples were ignited at 950ºC and the carbon dioxide evolved was measured with an infrared gas analyzer. Silt-clay samples were prepared by sieve separation followed by timed pipette extractions as described in Plumb (1981).

2.4 Contaminant Analysis

2.4.1 Sample Preparation

Samples were frozen at sea then shipped (overnight) to the analytical laboratory – NCCOS/Center for Coastal Environmental Health and Biomolecular Research (CCEHBR) in Charleston SC – where they were then kept at ≤ -20°C until analyzed. A 24-hour thawing period was used to bring sample temperature to approximately +4°C. Composited sediment samples were re-homogenized prior to obtaining sample aliquots. Separate aliquots were drawn for each of the contaminant tests. For metals analysis, sediments were prepared using microwave-assisted extraction (EPA Method 3052) while organic samples were prepared using ultrasonic extraction (EPA Method 3550a). All results were reported in dry weight units.

Fish samples were frozen at sea then shipped (overnight) to the CCEHBR laboratory where they were kept at ≤-20°C until analyzed. Samples were partially thawed prior to dissection and individuals were filleted for muscle tissue with skin and scales intact. Fillets were blended to create a homogenate from which aliquots were retrieved. A separate aliquot was drawn for each contaminant group. The homogenized tissue sample was split into an organic (pre-cleaned glass container) and inorganic (pre-cleaned polypropylene container) portion and stored at - 40 ºC until extraction or digestion.

A percent dry-weight determination was made gravimetrically on an aliquot of the wet sediment and tissues. Table 1 provides a list of all contaminants that were analyzed.

2.4.2 Inorganic Sample Digestion and Analysis

Dried sediment was ground with a mortar and pestle and transferred to a 20 mL plastic screw-top container. A 0.25-g sub-sample of the ground material was transferred to a Teflon-lined digestion vessel and digested in 5mL of concentrated nitric acid using microwave digestion. The sample was brought to a fixed volume of 50mL in a volumetric flask with deionized water and stored in a 50-mL polypropylene centrifuge tube until instrumental analysis of Li, Be, Al, Fe, Mg, Ni, Cu, Zn, Cd, and Ag. A second 0.25-g sub-sample was transferred to a Teflon-lined digestion vessel and digested in 5mL of concentrated nitric acid and 1mL of concentrated hydrofluoric acid in a microwave digestion unit. The sample was then evaporated on a hotplate at 225°C to near dryness and 1mL of nitric acid was added. The sample was brought to a fixed volume of 50mL in a volumetric flask with deionized water and stored in a 50-mL polypropylene centrifuge tube until instrumental analysis for V, Cr, Co, As, Sn, Sb, Ba, Tl, Pb, and U. Selenium was analyzed by hotplate digestion using a 0.25-g sub-sample and 5mL of concentrated nitric acid. Each sample was brought to a fixed volume of 50mL in a volumetric flask with deionized water and stored in a 50-mL polypropylene centrifuge tube until instrumental analysis. Additionally, 2-3g of wet tissue were microwave digested in Teflon-lined digestion vessels using 10mL of concentrated nitric acid along with 2mL of hydrogen peroxide. Digested samples were brought to a fixed volume with deionized water in graduated polypropylene centrifuge tubes and stored until analysis. A separate inorganic aliquot was used for mercury analysis. Approximately 0.5g of wet sediment or tissue was analyzed on a Milestone DMA-80 Direct Mercury Analyzer.

All remaining elemental analysis was performed using an Inductively Coupled Plasma Mass Spectrometry (ICP-MS) except for silver, which was determined using Graphite Furnace Atomic Absorption (GFAA) spectroscopy. Data quality was controlled by using a series of blanks, spiked solutions, and standard reference materials including NRC MESS-3 (Marine Sediments) and NIST 1566b (freeze dried mussel tissue).

2.4.3 Organic Extraction and Analysis

An aliquot (10g sediment or 5g tissue wet weight) was extracted with anhydrous sodium sulfate using Accelerated Solvent Extraction (ASE) in either 1:1 methylene chloride:acetone for sediments or 100% dichlormethane for tissues (Schantz 1997). Following extraction, samples were dried and cleaned using Gel Permeation Chromatography and Solid Phase Extraction to remove lipids and then solvent-exchanged into hexane for analysis. Samples were analyzed for PAHs, PBDEs, PCBs (by congener), and a suite of chlorinated pesticides using appropriate GC/MS technology. Data quality was ensured by using a series of spiked blanks, reagent blanks, and appropriate standard reference materials including NIST 1944 (sediments) and NIST 1566b (muscle tissue).

Table 1. List of target contaminants analyzed in coastal-ocean and estuarine sediment and tissue samples.

Polycyclic Aromatic Hydrocarbons (PAHs)	***Polychlorinated Biphenyls (PCBs)***
1-Methylnaphthalene	PCB 103 (2,2',4,5',6-Pentachlorobiphenyl)
1-Methylphenanthrene	PCB 104 (2,2',4,6,6'-Pentachlorobiphenyl)
2,3,5-Trimethylnaphthalene	PCB 105 (2,3,3',4,4'-Pentachlorobiphenyl)
2,6-Dimethylnaphthalene	PCB 106/118 Mixture
2-Methylnaphthalene	PCB 107/108 Mixture
Acenaphthene	PCB 110 (2,3,3',4',6-Pentachlorobiphenyl)
Acenaphthylene	PCB 114 (2,3,4,4',5-Pentachlorobiphenyl)
Anthracene	PCB 119 (2,3',4,4',6-Pentachlorobiphenyl)
Benz[a]anthracene	PCB 12 (3,4-Dichlorobiphenyl)
Benzo[a]pyrene	PCB 123 (2,3',4,4',5'-Pentachlorobiphenyl)
Benzo[b]fluoranthene	PCB 126 (3,3',4,4',5-Pentachlorobiphenyl)
Benzo[e]pyrene	PCB 128/167 Mixture
Benzo[g,h,i]perylene	PCB 130 (2,2',3,3',4,5'-Hexachlorobiphenyl)
Benzo[k]fluoranthene	PCB 132/168 Mixture
Biphenyl	PCB 138/163/164 Mixture
Chrysene	PCB 141 (2,2',3,4,5,5'-Hexachlorobiphenyl)
Dibenz[a,h]anthracene	PCB 146 (2,2',3,4',5,5'-Hexachlorobiphenyl)
Dibenzothiophene	PCB 149 (2,2',3,4',5',6-Hexachlorobiphenyl)
Fluoranthene	PCB 15 (4,4'-Dichlorobiphenyl)
Fluorene	PCB 151 (2,2',3,5,5',6-Hexachlorobiphenyl)
Indeno[1,2,3-c,d]pyrene	PCB 153 (2,2',4,4',5,5'-Hexachlorobiphenyl)
Naphthalene	PCB 154 (2,2',4,4',5,6'-Hexachlorobiphenyl)
Perylene	PCB 156 (2,3,3',4,4',5-Hexachlorobiphenyl)
Phenanthrene	PCB 157 (2,3,3',4,4',5'-Hexachlorobiphenyl)
Pyrene	PCB 158 (2,3,3',4,4',6-Hexachlorobiphenyl)
Pesticides	PCB 159 (2,3,3',4,5,5'-Hexachlorobiphenyl)
2,4'-DDD	PCB 169 (3,3',4,4',5,5'-Hexachlorobiphenyl)
2,4'-DDE	PCB 170/190 Mixture
2,4'-DDT	PCB 172 (2,2',3,3',4,5,5'-Heptachlorobiphenyl)
4,4'-DDD	PCB 174 (2,2',3,3',4,5,6'-Heptachlorobiphenyl)
4,4'-DDE	PCB 177 (2,2',3,3',4,5',6'-Heptachlorobiphenyl)
4,4'-DDT	PCB 18 (2,2',5-Trichlorobiphenyl)
Aldrin	PCB 180 (2,2',3,4,4',5,5'-Heptachlorobiphenyl)
Alpha-chlordane	PCB 183 (2,2',3,4,4',5',6-Heptachlorobiphenyl)
Chlorpyrifos	PCB 184 (2,2',3,4,4',6,6'-Heptachlorobiphenyl)
Dieldrin	PCB 187 (2,2',3,4',5,5',6-Heptachlorobiphenyl)
Endosulfan I	PCB 188 (2,2',3,4',5,6,6'-Heptachlorobiphenyl)
Endosulfan II	PCB 189 (2,3,3',4,4',5,5'-Heptachlorobiphenyl)
Endosulfan Sulfate	PCB 193 (2,3,3',4',5,5',6-Heptachlorobiphenyl)
Heptachlor	PCB 194 (2,2',3,3',4,4',5,5'-Octachlorobiphenyl)
Heptachlor epoxide	PCB 195 (2,2',3,3',4,4',5,6-Octachlorobiphenyl)
Hexachlorobenzene	PCB 198 (2,2',3,3',4,5,5',6-Octachlorobiphenyl)
Lindane	PCB 2 (3-Chlorobiphenyl)
Mirex	PCB 20 (2,3,3'-Trichlorobiphenyl)
Trans-nonachlor	PCB 200/201 Mixture
	PCB 202 (2,2',3,3',5,5',6,6'-Octachlorobiphenyl)
	PCB 206 (2,2',3,3',4,4',5,5',6-Nonachlorobiphenyl)
	PCB 207 (2,2',3,3',4,4',5,6,6'-Nonachlorobiphenyl)
	PCB 209 (2,2',3,3',4,4',5,5',6,6'-Decachlorobiphenyl)

	PCB 26 (2,3',5-Trichlorobiphenyl)
Metals	PCB 28 (2,4,4'-Trichlorobiphenyl)
Aluminum	PCB 29 (2,4,5-Trichlorobiphenyl)
Antimony	PCB 3 (4-Chlorobiphenyl)
Arsenic	PCB 31 (2,4',5-Trichlorobiphenyl)
Barium	PCB 37 (3,4,4'-Trichlorobiphenyl)
Beryllium	PCB 44 (2,2',3,5'-Tetrachlorobiphenyl)
Cadmium	PCB 45 (2,2',3,6-Tetrachlorobiphenyl)
Chromium	PCB 48 (2,2',4,5-Tetrachlorobiphenyl)
Cobalt	PCB 5/8 Mixture
Copper	PCB 50 (2,2',4,6-Tetrachlorobiphenyl)
Iron	PCB 52 (2,2',5,5'-Tetrachlorobiphenyl)
Lead	PCB 56/60 Mixture
Lithium	PCB 61/74 Mixture
Manganese	PCB 63 (2,3,4',5-Tetrachlorobiphenyl)
Mercury	PCB 66 (2,3',4,4'-Tetrachlorobiphenyl)
Nickel	PCB 69 (2,3',4,6-Tetrachlorobiphenyl)
Selenium	PCB 70 (2,3',4',5-Tetrachlorobiphenyl)
Silver	PCB 76 (2,3',4',5'-Tetrachlorobiphenyl)
Thallium	PCB 77 (3,3',4,4'-Tetrachlorobiphenyl)
Tin	PCB 81 (3,4,4',5-Tetrachlorobiphenyl)
Uranium	PCB 82 (2,2',3,3',4-Pentachlorobiphenyl)
Vanadium	PCB 84 (2,2',3,3',6-Pentachlorobiphenyl)
Zinc	PCB 87/115 Mixture
	PCB 88 (2,2',3,4,6-Pentachlorobiphenyl)
	PCB 89/90/101 Mixture
	PCB 9 (2,5-Dichlorobiphenyl)
	PCB 92 (2,2',3,5,5'-Pentachlorobiphenyl)
	PCB 95 (2,2',3,5',6-Pentachlorobiphenyl)
	PCB 99 (2,2',4,4',5-Pentachlorobiphenyl)

2.5 Toxicity Analysis

Microtox® assays were conducted using the standardized solid-phase test protocols (Microbics Corporation 1992) and a Microtox® Model 500 analyzer (Strategic Diagnostics Inc., CA). In this assay, sediment was homogenized and a 7.0 – 7.1-g sediment sample was used to make a series of sediment dilutions with 3.5% NaCl diluent, which were incubated for 10 minutes at 15ºC. Luminescent bacteria (*Vibrio fischeri*) were then added to the test concentrations. The liquid phase was filtered from the sediment phase and bacterial post-exposure light output was measured using Microtox® Omni Software. An EC50 value (the sediment concentration that reduced light output by 50% relative to the controls) was calculated for each sample. Triplicate samples were analyzed simultaneously. Sediment samples were evaluated using criteria developed by Ringwood et al. (1997) to account for grain-size variations.

2.6 Benthic Community Analysis

Once in the laboratory, samples were transferred from formalin to 70% ethanol. Macroinfaunal invertebrates were sorted from the sample debris under a dissecting microscope and identified to the lowest practical taxon (usually species). Data were used to compute density (m^{-2}) of total fauna (all species combined), densities of numerically dominant species (m^{-2}), numbers of species, and H' diversity (Shannon and Weaver 1949) derived with base-2 logarithms.

2.7 Data Analysis

A probabilistic, stratified-random sampling design was used in these surveys in order to provide a basis for making unbiased statistical estimates of the spatial extent (% area) of condition within the survey area, with 95 % confidence intervals, based on the status of various measured ecological indicators and corresponding thresholds of interest (Table 2). A similar approach has been applied throughout EPA's EMAP, related NCA programs, and other coastal-ocean surveys (e.g., Summers et al. 1995; Strobel et al. 1995; Hyland et al. 1996; USEPA 2004, 2006; Nelson et al. 2008; Balthis et al. 2009; Cooksey et al. 2010). Results of the above type of spatial estimates are presented throughout this report as the percent area of the South Florida Continental Shelf within specified ranges of a particular indicator. Thresholds defining such ranges (see Table 1) include, where possible, those having known biological significance (e.g., dissolved oxygen < 2 mg L^{-1}). Additional data summaries presenting key distributional properties (e.g., mean, range) and other basic data tabulations are provided as well. Data presented graphically in this report are primarily in the form of cumulative distribution functions (CDFs) and pie charts. These are useful tools for portraying the percentage of coastal area corresponding to varying levels of a given indicator across the full range of its observed values and for estimating the percentage of area falling below or above some designated threshold of interest. This is a useful feature for management applications; for example, if valid thresholds can be defined for a particular indicator or suite of indicators, they could be used as ecosystem quality targets for monitoring the system and triggering any necessary management actions.

The biological significance of sediment contamination was evaluated by comparing measured chemical concentrations in sediments to corresponding Effects Range-Low (ERL) and Effects Range-Median (ERM) sediment quality guideline (SQG) values developed by Long et al. (1995) and listed here in Table 3. The ERL values are lower-threshold bioeffect limits, below which adverse effects on sediment–dwelling organisms are not expected to occur. ERM values represent upper-threshold concentrations, above which bioeffects are likely to occur in some sediment-dwelling species. Overall sediment contamination from multiple chemicals was expressed as the mean ERM quotient (ERM-Q) (Long et al. 1998; Long and MacDonald 1998; Hyland et al. 1999), which is the mean of the ratios of individual chemical concentrations in a sample relative to corresponding ERM values.

The biological significance of fish tissue contamination was evaluated from a human-health perspective using risk-based consumption limits for cancer and non-cancer (chronic systemic effects) endpoints derived by U.S. EPA (2000) for a variety of organic and inorganic contaminants (Table 4). These risk based consumption limits also serve as surrogate benchmark values for fish health since comprehensive ecological thresholds for contaminant levels in juvenile and adult fish do not currently exist for the fish species evaluated in this report (U.S. EPA 2012). Concentrations of contaminants measured in fish tissues were compared to the corresponding endpoints for cancer and chronic health risks associated with the consumption of four 8-ounce meals per month for the general adult population. Fish tissue contamination data were only available for a subset of stations; therefore, tissue contaminant data were not evaluated on a percent areal basis.

Table 2. Thresholds used for classifying samples relative to various environmental indicators.

Indicator	Threshold	Reference
<u>Water Quality</u>		
Salinity (psu)	< 5 = Oligohaline 5 – 18 = Mesohaline >18 – 30 = Polyhaline > 30 = Euhaline	Carriker 1967
DO (mg/L)	< 2 = Low (Poor) 2 – 5 = Moderate (Fair) > 5 = High (Good)	U. S. EPA 2008; Diaz and Rosenberg 1995
DIN/DIP	> 16 = phosphorus limited < 16 = nitrogen limited	Geider and LaRoche 2002
$\Delta\delta_T$	Strong Vertical Stratification: > 2	Nelson et al. 2008
<u>Sediment Quality</u>		
Silt-Clay Content (%)	> 80 = Mud 20 – 80 = Muddy Sand < 20 = Sand	U. S. EPA 2008
TOC Content (mg/g)	> 50 = High (Poor) 20 – 50 = Moderate (Fair) < 20 = Low (Good)	U. S. EPA 2008
	> 35 = High (Poor)	Hyland et al. 2005
Overall chemical contamination	≥ 1 ERM value exceeded *OR* mERM-Q > 0.058 = High (Poor); ≥ 5 ERL values exceeded *OR* 0.02 < mERM-Q ≤ 0.058 = Moderate (Fair); No ERMs exceeded *AND* < 5 ERLs exceeded *AND* mERM-Q ≤ 0.02 = Low (Good)	U. S. EPA 2008; Hyland et al. 1999

Table 2 (continued).

Indicator	Threshold	Reference
Individual chemical contaminant concentrations	> ERM = High probability of bioeffects < ERL = Low probability of bioeffects	Long et al. 1995
Toxicity (Microtox®)	Silt-clay < 20 %: Toxic if EC50 < 0.5 % Silt-clay ≥ 20 %: Toxic if EC50 < 0.2 %	Ringwood et al. 1997
<u>Biological Condition</u>		
Benthic Community (potential degraded condition)	Low values of species richness, H′, and density (defined for the purpose of this analysis as the lower 10th percentile of observed values) combined with evidence of poor sediment or water quality was defined as: ≥ 1 chemical in excess of ERMs, TOC > 50 mg/g, or dissolved oxygen in near-bottom water < 2 mg/L.	Cooksey et al. 2010
Chemical Contaminants in Fish Tissues	≥ 1 chemical exceeded Human Health upper limit = High (Poor) ≥ 1 chemical within Human Health risk range = Moderate (Fair) All chemicals below Human Health lower risk limit = Low (Good)	U. S. EPA 2008
Individual chemical contaminants in fish tissues	Non-cancer (chronic systemic effects) endpoints based on consumption of four 8-ounce meals per month (general adult population). Cancer risk endpoints (1 in 100,000 risk level) based on consumption of four 8-ounce meals per month (general adult population).	U. S. EPA 2000

Table 3. ERM and ERL guidance values in sediments (Long et al. 1995).

Chemical	ERL	ERM
Metals (µg/g)		
Arsenic	8.2	70
Cadmium	1.2	9.6
Chromium	81	370
Copper	34	270
Lead	46.7	218
Mercury	0.15	0.71
Nickel	20.9	51.6
Silver	1	3.7
Zinc	150	410
Organics (ng/g)		
Acenaphthene	16	500
Acenaphthylene	44	640
Anthracene	85.3	1100
Fluorene	19	540
2-Methylnaphthalene	70	670
Naphthalene	160	2100
Phenanthrene	240	1500
Benzo[a]anthracene	261	1600
Benzo[a]pyrene	430	1600
Chrysene	384	2800
Dibenz[a,h]Anthracene	63.4	260
Fluoranthene	600	5100
Pyrene	665	2600
Low molecular weight PAHs	552	3160
High molecular weight PAHS	1700	9600
Total PAHs	4020	44800
4,4-DDE	2.2	27
Total DDT	1.58	46.1
Total PCBs	22.7	180

Table 4. Risk based EPA advisory guidelines for recreational fishers (US EPA 2000). Concentration ranges represent the non-cancer health endpoint risk for four 8-ounce fish meals per month.

	Non-cancer Health Endpoint[a]	Cancer Health Endpoint[b]
Metals (µg/g)		
Arsenic (inorganic)[c]	>0.35 – 0.70	>0.0078 – 0.016
Cadmium	>0.35 – 0.70	
Mercury (methylmercury)[d]	>0.12 – 0.23	
Selenium	>5.90 – 12.00	
Organics (ng/g)		
Chlordane	>590 – 1200	>34 – 67
Chlorpyriphos	>350 – 700	
DDT (total)	>59 – 120	>35 – 69
Dieldrin	>59 – 120	>0.73 – 1.5
Endosulfan	>7000 – 14000	
Heptachlor epoxide	>15 – 31	>1.3 – 2.6
Hexachlorobenzene	>940 – 1900	>7.3 – 15.0
Lindane	>350 – 700	>9.0 – 18
Mirex	>230 – 470	
Toxaphene	>290 – 590	>11.0 – 21
PAHs (benzo[a]pyrene)		>1.6 – 3.2[e]
PCB (total)	>23 – 47	>5.9 – 12.0

[a] Range of concentrations for non-cancer health endpoints are based on the assumption that consumption over a lifetime of four 8-oz meals per month would not generate a health risk.
[b] Range of concentrations for cancer health endpoints are based on the assumption that consumption over a lifetime of four 8-oz meals per month would yield a lifetime cancer risk no greater than an acceptable risk of 1 in 100,000.
[c] Inorganic arsenic, the form considered toxic, estimated as 2% of total arsenic.
[d] Because most mercury present in fish and shellfish tissue is present primarily as methylmercury and because of the relatively high cost of analyzing for methylmercury, the conservative assumption was made that all mercury is present as methylmercury (U. S. EPA, 2000).
[e] A non-cancer concentration range for PAHs does not exist.

3.0 Results and Discussion

3.1 Depth and Water Quality

3.1.1 Depth and General Water Characteristics: Temperature, salinity, water-column stratification, DO, pH, water clarity

Key bottom-water characteristics throughout the region (Figure 2, Table 5, Appendix A, B, C) can be summarized as follows: (1) water depths ranging from 7.0 – 83.4 m and averaging 34.9 m (water depths were not corrected to Mean Low Low Water); (2) a narrow range of euhaline salinity (PSU) values of 35.7 – 37.0 (overall mean of 36.5); (3) generally high DO levels ranging from 3.5 – 7.5 mg L^{-1} and averaging 6.2 mg L^{-1}; (4) typically warm temperatures ranging from 18.9 – 27.4 °C and averaging 23.9 °C; (5) a wide range of bottom pH levels from 5.8 – 10.4 and averaging 8.0; and (6) low levels of surface-water total suspended solids (TSS) ranging from 2.05 – 9.79 mg L^{-1} and averaging 4.38 mg L^{-1}.

Water-column stratification expressed as $\Delta\sigma_t$, an index of the variation between surface and bottom water densities, was calculated from temperature and salinity data. The index is the difference between the computed bottom and surface σ_t values, where σ_t is the density of a parcel of water with a given salinity and temperature relative to atmospheric pressure (Nelson et al. 2008). The $\Delta\sigma_t$ index ranged from 0 to 4.57. Ninety-eight percent of the area of waters of the south Florida shelf had $\Delta\sigma_t$ index values less than 2, indicating weak vertical stratification of the water column (Table 5). One station, accounting for 0.2 percent of the area had $\Delta\sigma_t$ index values greater than 2, indicating strong vertical stratification of the water column. This station, 06, was 60m deep and located in the southwest corner of the sampling region along the outflow of the Loop Current (Figure 1, Appendix A; Hetland et al. 1999).

The majority of the South Florida coastal waters had bottom-water DO levels in the high range (> 5 mg L^{-1}) considered good for marine life (Table 4). DO levels in bottom-waters exceeded this upper threshold across almost all coastal-ocean waters (98.2%) and only 1.2% (2 stations) of the shelf bottom-waters had moderate levels of DO between 2 and 5 mg L^{-1}. No part of the south Florida shelf waters had DO levels below 2 mg L^{-1} during this survey. The two stations with moderate DO levels (2 – 5 mg L^{-1}) were both located along the eastern boundary of the sampling area, along the outflow of the Florida Straits (Figure 4).

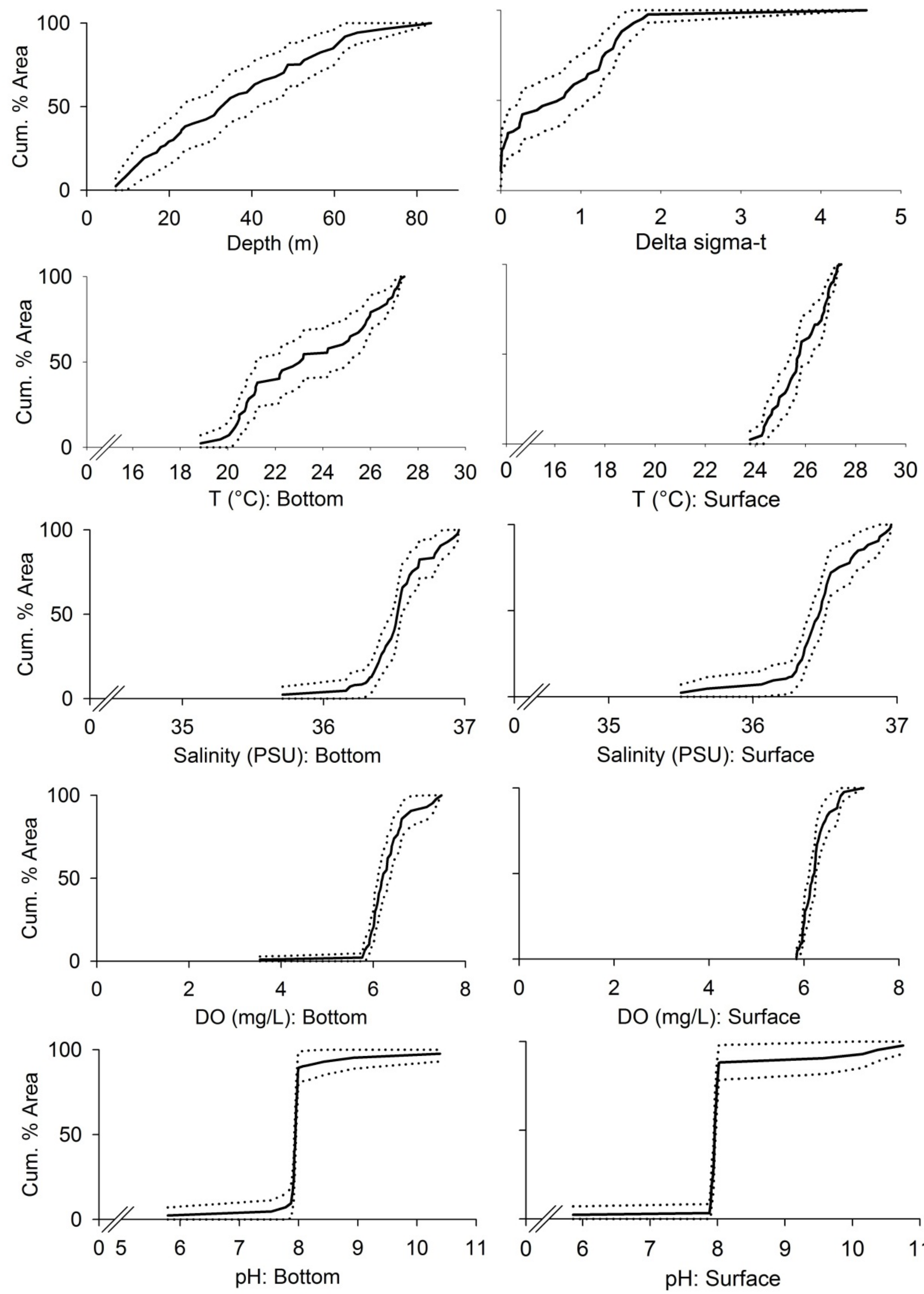

Figure 2. Percent area (solid lines) and 95% Confidence Intervals (dotted lines) of South Florida coastal ocean depth and selected water-quality characteristics.

Table 5. Summary of depth and water characteristics for near-bottom (within 3-5 m of bottom) and near-surface (0.5 – 2 m) waters from 50 South Florida coastal ocean sites.

	Near-Bottom					Near-Surface				
	Mean	Range	CDF 10^{th} pctl	CDF 50^{th} pctl	CDF 90^{th} pctl	Mean	Range	CDF 10^{th} pctl	CDF 50^{th} pctl	CDF 90^{th} pctl
Depth	34.9	7.0 – 83.4	10.0	32.8	62.0	--	--	--	--	--
Δσt	0.69	0 – 4.57	0	0.69	1.59	--	--	--	--	--
Temperature (°C)	23.9	18.9 – 27.4	20.2	23.1	27.0	26.0	23.8 – 27.4	24.4	25.7	27.1
Salinity (psu)	36.5	35.7 – 37.0	36.3	36.5	36.8	36.4	35.5 – 37.0	36.2	36.4	36.8
DO (mg/L)	6.2	3.5 – 7.5	5.9	6.2	6.8	6.2	5.8 – 7.2	5.9	6.2	6.7
pH	8.0	5.8 – 10.4	7.9	8.0	8.1	8.1	5.9 – 10.7	7.90	7.96	9.0
DIN (mg/L)	0.01	0 – 0.08	0	0	0.01	0.00	0 – 0.04	0	0	0.01
DIP (mg/L)	0.00	0 – 0.02	0	0	0.01	0.00	0 – 0.03	0	0	0
Chl a (µg/L)	0.38	0.1 – 1.1	0.18	0.34	0.63	0.20	0.04 – 0.99	0.05	0.1	0.4
TSS (mg/L)	4.97	2.18 – 14.27	2.80	4.80	6.80	4.38	2.05 – 9.79	2.53	3.64	7.10

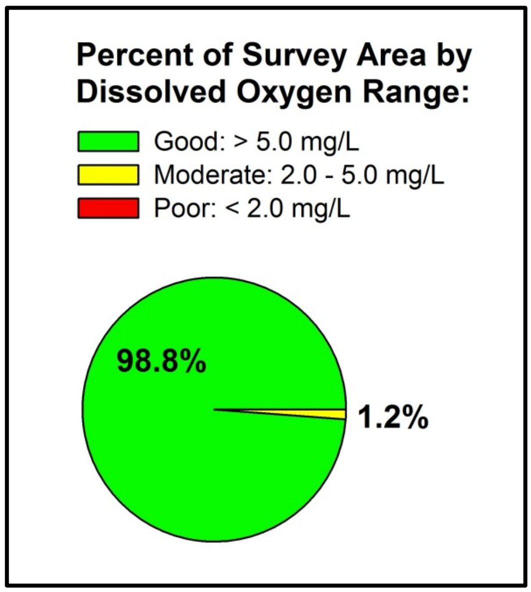

Figure 3. Percent area of South Florida coastal ocean waters within specified ranges of DO concentrations.

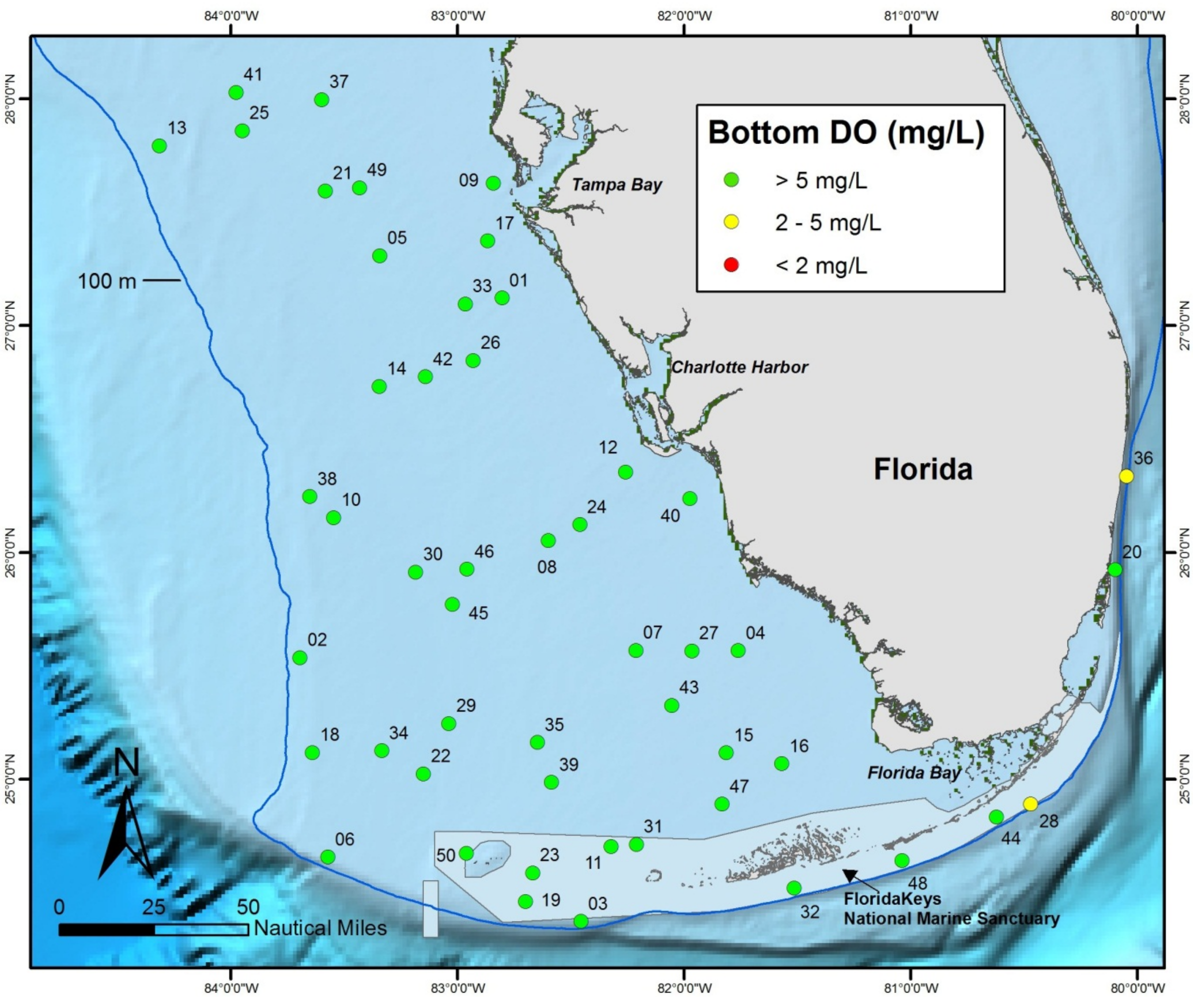

Figure 4. Spatial distribution of bottom dissolved oxygen levels in South Florida coastal ocean waters.

3.1.2 Nutrients and Chlorophyll

Surface-water concentrations of total dissolved inorganic nitrogen (DIN: nitrate + nitrite + ammonium as nitrogen) were very low ranging from 0 – 0.08 mg L^{-1} and averaging 0 mg L^{-1} (Figure 5, Table 5, Appendix B). The 50th percentile of the surface-water sampling area corresponded to a DIN concentration of 0 mg L^{-1} and the 90th percentile corresponded to a DIN concentration of 0.007 mg L^{-1}. Surface-water concentrations of dissolved inorganic phosphate (DIP: orthophosphate as phosphate) were even lower than DIN and ranged from 0 – 0.03 mg L^{-1} while averaging 0 mg L^{-1} (Figure 5, Table 5). The 50th percentile of the surface-water sampling area corresponded to a DIP concentration of 0 mg L^{-1} as did the 90th percentile. While nutrient enrichment and associated eutrophication are ongoing concerns within the estuarine areas adjacent to the south Florida shelf, including Florida Bay, nutrient levels remain low within the surrounding shelf environment (Rudnick et al. 1999).

The ratio of DIN concentration to DIP concentration (N/P ratio) was calculated as an indicator of which nutrient may be controlling primary production at the 18 stations where DIP was found above the MDL for the analysis method used (Appendix B). A ratio above 16 is generally considered indicative of phosphorus limitation, and a ratio below 16 is considered indicative of nitrogen limitation (Geider and La Roche 2002). The N/P ratio in surface waters ranged from 0.36 to 26.3 and averaged 4.8. Of the 40% of the offshore survey area were N/P ratios were calculated 38% had N/P ratios < 16, indicative of a nitrogen limited environment, and 2% had N/P rations > 16, indicative of a phosphate limited environment. Consistent with these findings, the South Florida coastal ocean has previously been reported as being oligotrophic and primarily nitrogen limited (Vargo et al. 2008).

Chlorophyll *a* (Chl *a*) levels in surface waters ranged from 0.04 – 0.99 μg L^{-1} and averaged 0.20 μg L^{-1} (Figure 5, Table 5, Appendix B). The 50th percentile of the surface-water sampling area corresponded to a Chl *a* concentration of 0.09 μg L^{-1} and the 90th percentile corresponded to a Chl *a* concentration of 0.38 μg L^{-1}. All offshore stations, representing 100% of the offshore survey area, had Chl *a* below the 5.0 μg L^{-1} threshold used to denote the beginning of the high range for estuarine waters (U.S. EPA 2004). The 90^{th} percentile of the survey area had a Chl *a* concentration of 0.4 μg L^{-1} for surface-waters and those stations with Chl *a* values above this level were all located nearshore (Figure 6). Such low levels of Chl *a* are normal for the south Florida shelf environment, with the exception of algal bloom events (Del Castillo et al 2001, Redalje et al. 2008).

The amount of TSS in the water column has a direct effect on turbidity (a measure of water clarity) by causing the attenuation or scattering of light, though TSS itself is not a measure of turbidity. Generally as TSS increases, the water becomes murkier or more turbid. Excessively high turbidity and TSS may be harmful to marine life (e.g., by reducing light penetration and photosynthesis, increasing biological oxygen demand of high organic content, interfering with normal respiratory and feeding activities) and distract from the aesthetic value of a coastal area. TSS levels in both surface- and bottom-waters along the south Florida shelf were low (Figure 5, Table 5). The 50^{th} percentile of the survey area had a TSS concentration of 3.7 mg L^{-1} for surface-waters and 4.78 mg L^{-1} for bottom-waters.

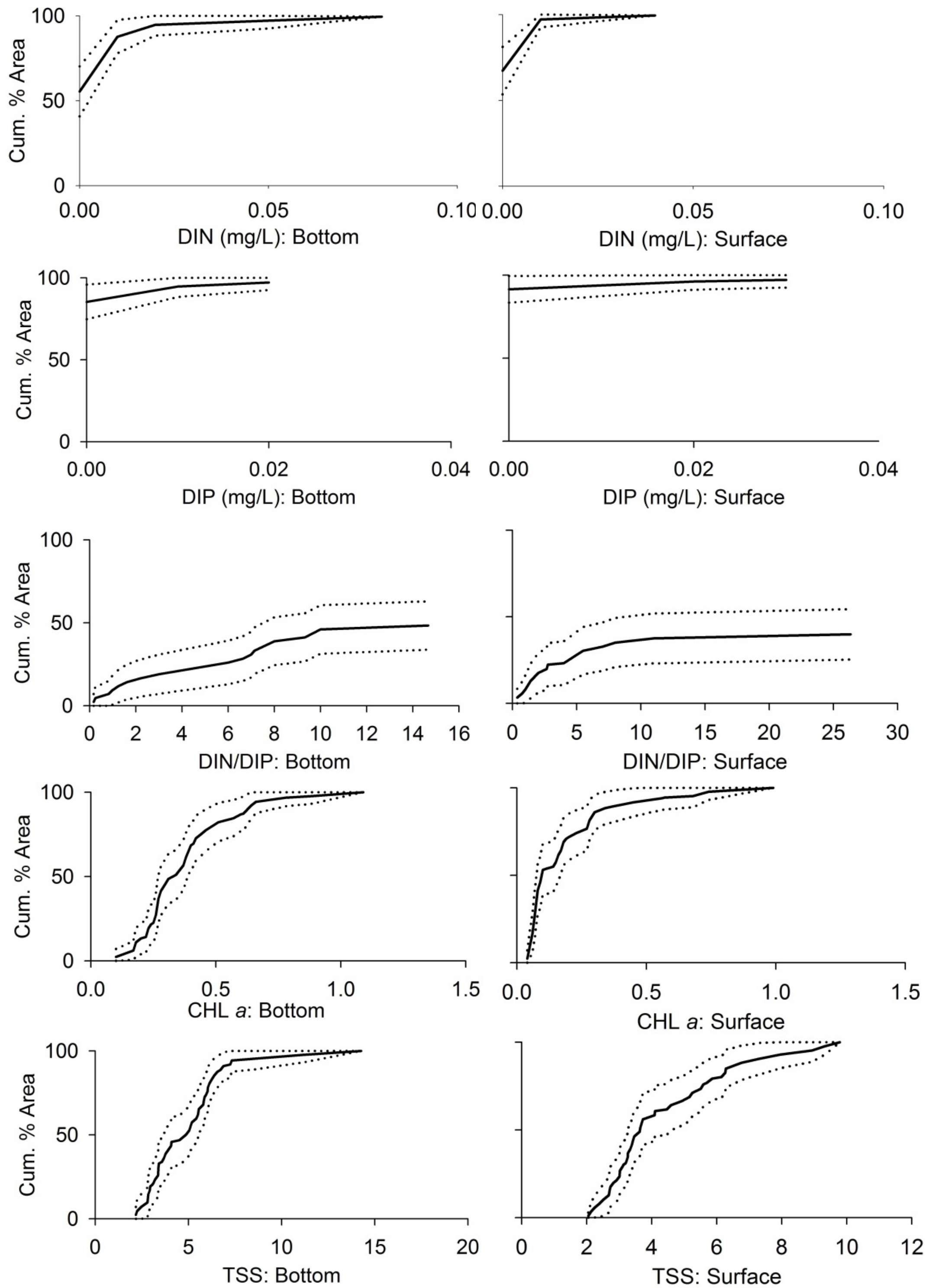

Figure 5. Percent area (solid lines) and 95% Confidence Intervals (dotted lines) of South Florida coastal ocean waters for nurtients, chlorophyll *a* and TSS concentrations.

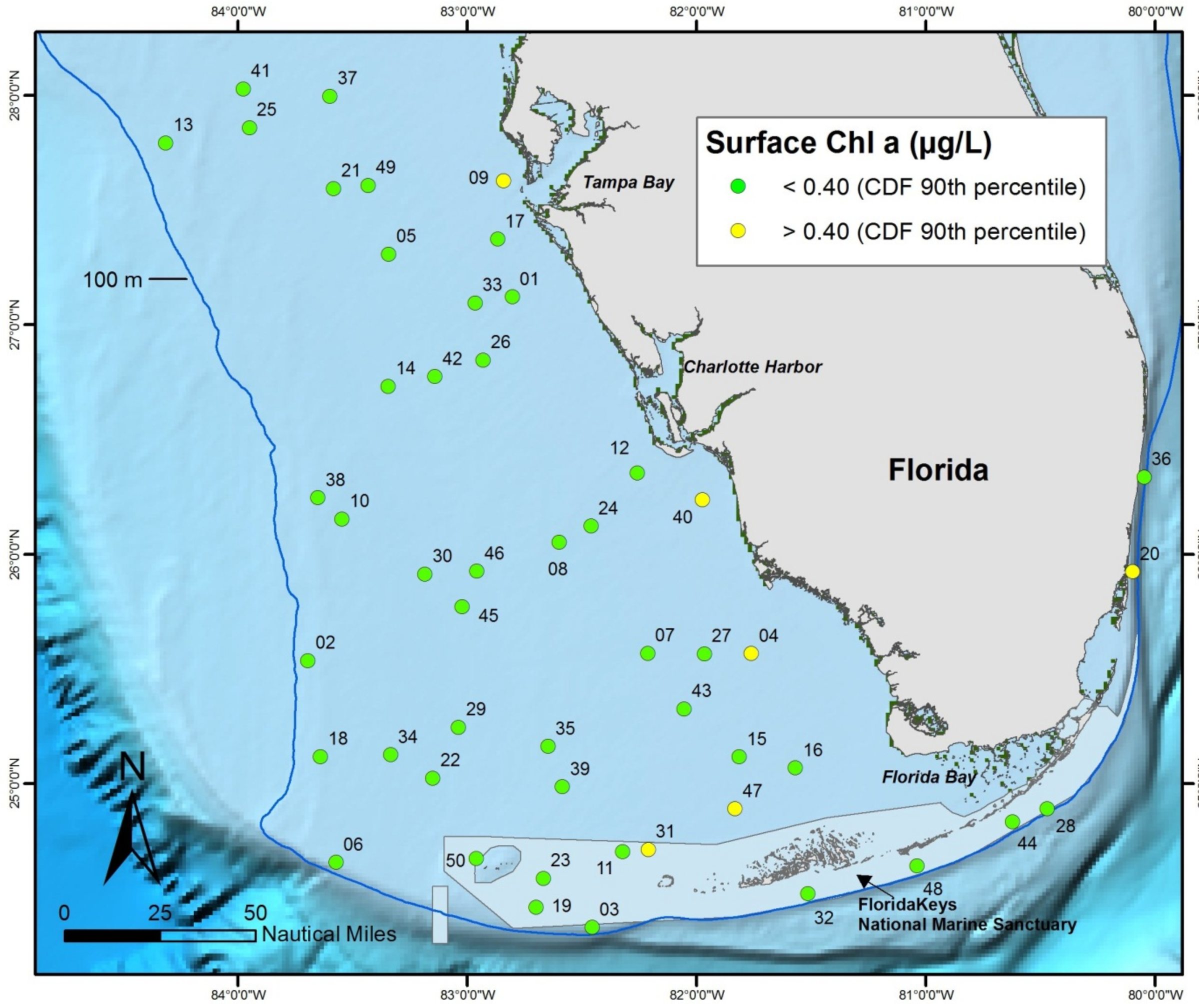

Figure 6. Spatial distribution of surface chlorophyll *a* levels in South Florida coastal ocean waters.

3.2 Sediment Quality

3.2.1 Grain Size and TOC

The percentage of silt-clay in sediments ranged from 0% to 79.3% and averaged 15% throughout the survey area (Table 6, Appendix A). None of the stations were composed of muds (> 80% silt-clay; Figure 7). In contrast, the majority of stations had some percent of gravel-size sediment particles present (Figure 8). Total organic carbon (TOC) in sediments exhibited a narrow range (3.8 to 6.8 mg g^{-1}) with an average concentration of 5.6 mg g^{-1} (Table 6). One hundred percent of the survey area had relatively low TOC levels of < 20 mg g^{-1} and thus none had high levels in excess of upper thresholds associated with a high risk of adverse effects on benthic fauna (> 50 mg g^{-1} cutpoint from USEPA 2008, or > 36 mg g^{-1} cutpoint from Hyland et al. 2005) (Figures 9 and 10).

Overall, the south Florida shelf is part of a large, ancient carbonate platform which is now dominated by coarse sand, shell hash, and coral rubble. There are, however, pockets within the larger shelf region which are dominated by muddy-sands. Two areas which stand out are the mid-shelf region extending from Key West and the Dry Tortugas north to the area off Tampa Bay as well as stations along the outer edge of FKNMS (28, 32, 44) in the Florida Straits (Figure 11).

Table 6. Summary of sediment characteristics from 50 South Florida continental shelf sites.

	Mean	Range	CDF 10^{th}%	CDF 50^{th}%	CDF 90^{th}%
TOC (mg g^{-1})	5.6	3.8 – 6.8	4.6	5.7	6.3
% silt-clay	15.0	0 – 79.3	0	1.0	40.8
Mean ERM-Q	0.011	0.003 – 0.021	0.006	0.012	0.016

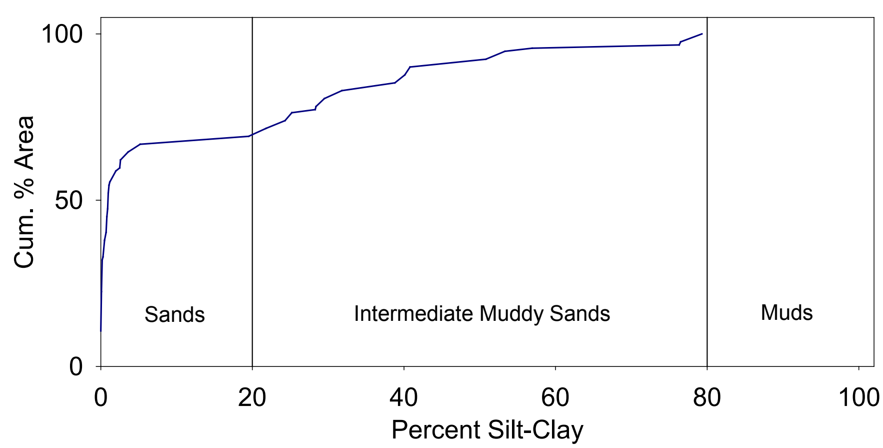

Figure 7. Percent area of South Florida shelf vs. percent silt-clay of sediment.

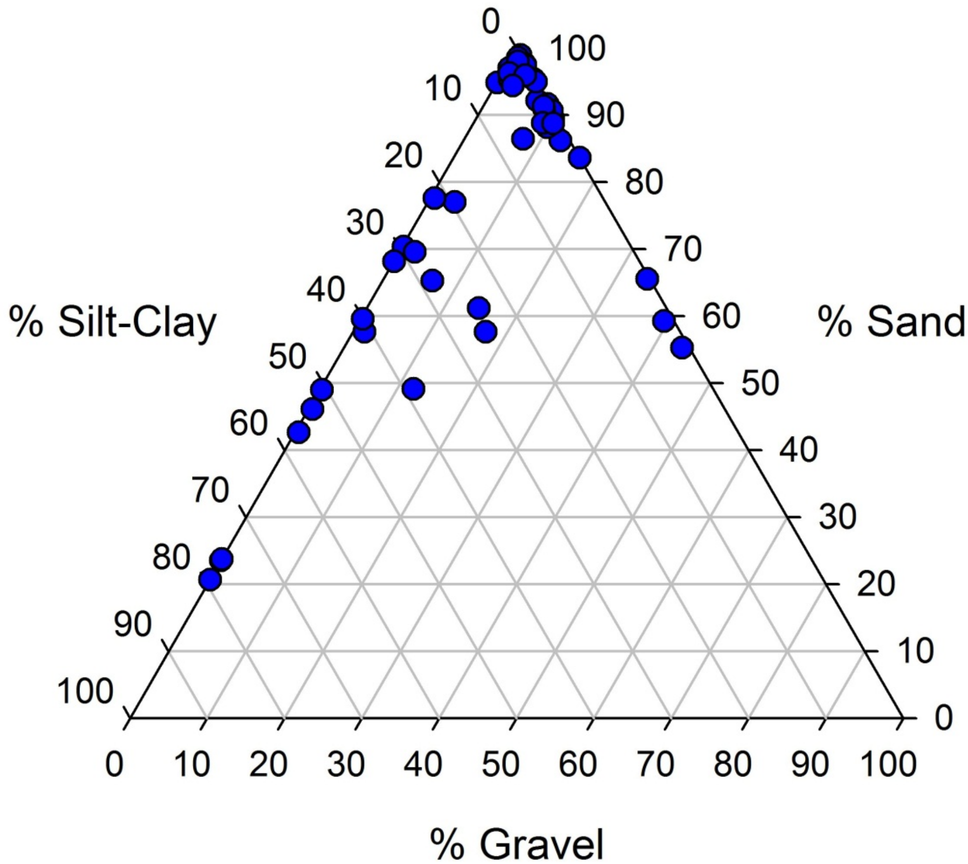

Figure 8. Distribution of percentages of gravel, sand, and silt-clay in surficial sediments.

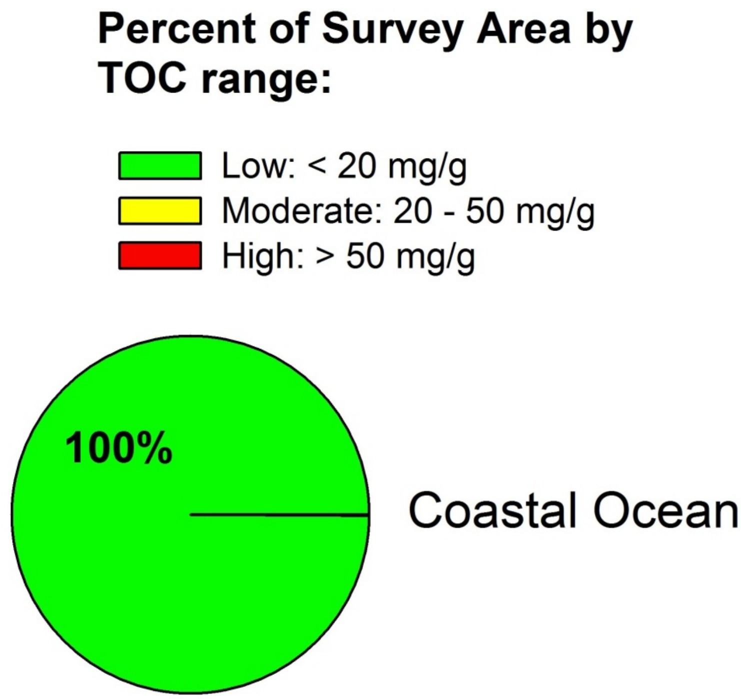

Figure 9. Percent area of South Florida shelf sediments within specified ranges of TOC levels.

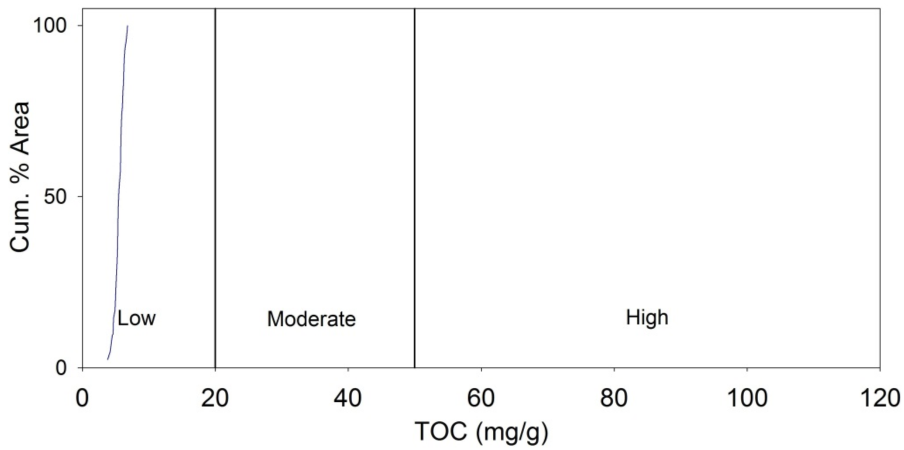

Figure 10. Percent area of South Florida continental shelf vs. TOC levels of sediment.

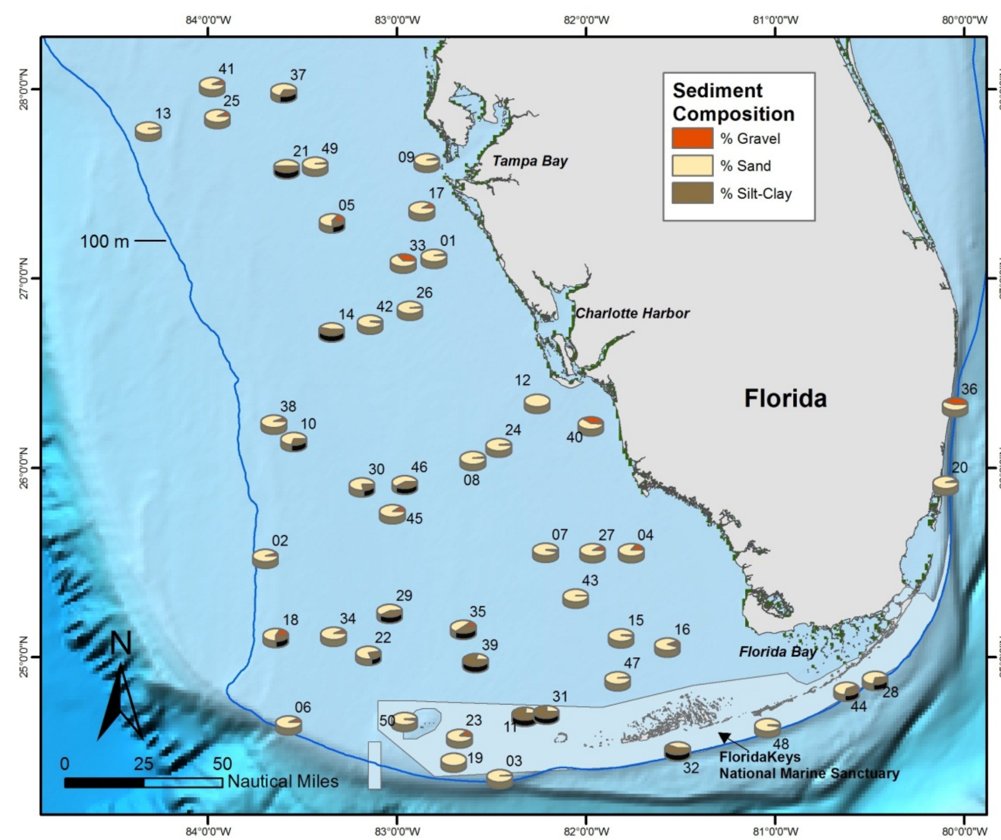

Figure 11. Percent gravel, sand and silt-clay composition of South Florida shelf sediments.

3.2.2 Chemical Contaminants in Sediments

Effects Range-Low (ERL) and Effects Range-Median (ERM) sediment quality guideline (SQG) values from Long et al. (1995) were used to help interpret the biological significance of observed chemical contaminant levels in sediments. ERL values are lower-threshold bioeffect limits, below which adverse effects of the contaminants on sediment-dwelling organisms are not expected to occur. In contrast, ERM values represent mid-range concentrations of chemicals above which adverse effects are more likely to occur. A list of 26 chemicals, or chemical groups, for which ERL and ERM guidelines have been developed is provided in Table 3 along with the corresponding SQG values (from Long et al. 1995). Any site with one or more chemicals that exceeded corresponding ERM values was rated as having poor sediment quality, any site with five or more chemicals between corresponding ERL and ERM values was rated as fair, and any site that had less than five ERLs exceeded and no ERMs exceeded was rated as good (sensu USEPA 2004).

Overall sediment contamination from multiple chemicals also was expressed as the mean ERM quotient (ERM-Q) (Long et al. 1998; Long and MacDonald 1998; Hyland et al. 1999), which is the mean of the ratios of individual chemical concentrations in a sample relative to corresponding ERM values (using all chemicals in Table 3 except nickel and total PAHs). Specific mean ERM-Qs for evaluating low versus high risks of stress in benthic communities have not been developed for offshore sediments of the south Florida shelf, but such sediment quality targets have been developed for the surrounding estuarine regions of the Gulf of Mexico and Atlantic coasts (Hyland et al. 2003). Thus, a mean ERM-Q cutpoint of 0.044, marking the beginning of the range associated with a high risk of degraded benthic condition in estuaries of the region (Hyland et al. 2003), was used as a rough guideline for evaluating sediment contaminant levels in this survey.

Sediments throughout the coastal-ocean survey area were relatively uncontaminated with all stations (100%) having contaminant concentrations in the low range with respect to the number of ERL/ERMs exceed (Table 7, Figure 12, Appendix D). Only one trace metal (cadmium) was found at moderate concentrations between corresponding ERL and ERM values, but no chemicals were found in excess of the higher-threshold ERM values (Table 7). ERL values were exceeded by cadmium at 19 of the 50 stations and none of these stations had more than one ERL exceedance. Mean ERM-Q values across the region were variable but low, ranging from 0.003 to 0.021 and averaging 0.011 (Table 6, Appendix D). None of the offshore sediments had mean ERM-Qs in the high range (i.e., >0.044).

Although chemical contaminants in these offshore sediments were at low background levels throughout the survey area, PAHs and PCBs were found above minimum detection limits at numerous locations (Figures 13 and 14). Low levels of PAHs were distributed throughout the survey area and PCBs were found at a smaller number of stations. These results are in marked contrast to conditions in the continental shelf sediments of the South Atlantic Bight, where no detectable PAHs or PCBs were found (Cooksey et al. 2010), and the Mid-Atlantic Bight, where only a subset of individual PAHs were found at levels above minimum detection limits (Balthis et al. 2009).

Results of this study were compared to sediment contaminant data from South Florida estuaries collected as part of the EPA National Coastal Assessment program, 2000-2004 (available at www.epa.gov). Means for metals were similar for both the estuaries and offshore sediments (Table 7). Given the short half-lives of many pesticides it is not surprising that multiple pesticides were found within estuaries, but not offshore. In contrast, both PAHs and PCBs were found at higher concentrations throughout the offshore region relative to South Florida estuaries, though still below bioeffect guidelines, as measured in the NCA. The low but detectable PAH levels offshore may reflect the high incidence of natural oil seeps in the Gulf of Mexico. In addition to the NCA data there are a variety of peer-reviewed publications which have focused on sediment contaminant issues within South Florida estuaries (Kannan et al. 1998, Long et al. 2002, Caccia et al. 2003, Grabe and Barron 2003). These surveys indicate the presence of hotspots with elevated sediment contamination levels in portions of Tampa Bay and Biscayne Bay with broader estuarine areas having much lower contaminant levels.

Table 7. Summary of chemical contaminant concentrations in south Florida shelf sediments ('N/A' = no corresponding ERL or ERM available). Estuarine data from West Indian Province National Coastal Assessment (WI NCA), South Florida stations only, mean chemical contaminant concentrations for 2000-2004.

Analyte	Mean	Range	Concentration > ERL < ERM # Stations	Concentration > ERM # Stations	WI NCA 2000-2004[2] Mean
Metals (% dry wt.)					
Aluminum	0.25	0.05 – 0.62	-	-	-
Iron	0.24	0.07 – 0.93	-	-	-
Trace Metals (µg/g)					
Antimony	0.697	0 – 1.44	-	-	2.18
Arsenic	2.7	0.5 – 7.9	0	0	2.36
Barium	13.0	6.3 – 32.6	-	-	-
Beryllium	0.04	0 – 0.22	-	-	
Cadmium	0.83	0.03 – 3.57	19	0	0.38
Chromium	7.94	3.3 – 15.3	0	0	5.55
Copper	1.51	0 - 4.71	0	0	3.56
Lead	1.29	0.48 – 2.51	0	0	1.74
Lithium	4.13	0.88 – 7.57	-	-	-
Manganese	26.4	6.2 – 54.8	-	-	21.57
Mercury	0.007	0.0008 - 0.01	0	0	0.049
Nickel	4.66	0.24 – 6.59	0	0	2.71
Selenium	0.32	0 - 0.60	-	-	7.95
Silver	0	0	0	0	0.62
Thallium	0.08	0 – 0.18	-	-	-
Tin	0.41	0 – 1.46	-	-	3.78
Uranium	1.89	0.59 – 4.34	-	-	-
Vanadium	4.16	1.33 – 9.5	-	-	-
Zinc	7.28	2.3 - 34.3	0	0	2.97
PAHs (ng/g)					
Acenaphthene	0.05	0 – 0.49	0	0	0
Acenaphthylene	0.08	0 – 0.61	0	0	0
Anthracene	0.17	0 – 0.85	0	0	0
benz[a]anthracene	0.18	0 – 1.07	0	0	0
benzo[a]pyrene	0.24	0 – 2.07	0	0	0
benzo[b]fluoranthene	0.26	0 – 2.33	-	-	0.39
benzo[e]pyrene	0.39	0 – 1.5	0	0	-
Benzo[g,h,i]perylene	0.16	0 – 1.18	-	-	0
Benzo[j+k]fluoranthene	0.01	0 – 0.39	-	-	0.37
Biphenyl	0.45	0 – 5.13	-	-	0
Chrysene	0.21	0 – 1.67	0	0	0
Dibenz[a,h]Anthracene	0.26	0 – 2.83	0	0	1.15
Dibenzothiophene (Synfuel)	0.018	0 – 0.094	-	-	0
2,6-Dimethylnaphthalene	1.60	0 – 7.38	-	-	0
Fluoranthene	0.31	0 – 1.75	0	0	1.40
Fluorene	0.15	0 – 0.48	0	0	0.89
Indeno[1,2,3-c,d]Pyrene	1.13	0 – 5.17	-	-	1.13
Naphthalene	8.64	0 – 40.9	0	0	0.25
2-Methylnaphthalene	4.23	0 – 20.5	0	0	0
1-Methylnaphthalene	3.08	0 – 13.9	-	-	0
1-Methylphenanthrene	0.01	0 – 0.15	-	-	0

Analyte	Mean	Range	Concentration > ERL < ERM # Stations	Concentration > ERM # Stations	WI NCA 2000-2004[2] Mean
Perylene	0.42	0 – 5.52	-	-	-
Phenanthrene	0.52	0 – 1.14	0	0	0
Pyrene	0.32	0 – 1.96	0	0	0.48
1,6,7-Trimethylnaphthalene	0.28	0 – 1.11	-	-	-
Total Low Molecular Weight PAHs	19.3	0.09 – 90.3	0	0	-
Total High Molecular Weight PAHs	3.90	0 – 19.9	0	0	-
Total PAHs	23.2	0.09 – 93.7	0	0	0.31
PBDEs (ng/g)					
Total PBDEs	0	0 - 0	-	-	-
PCBs (ng/g)[1]					
PCB 194	0.004	0 – 0.193	-	-	-
PCB 174	0.005	0 – 0.253	-	-	-
PCB 26	0.005	0 – 0.268	-	-	-
PCB 110	0.007	0 – 0.328	-	-	0
PCB 89/90/101 Mixture	0.007	0 – 0.331	-	-	-
PCB 170/190 Mixture	0.007	0 – 0.352	-	-	-
PCB 187	0.008	0 – 0.409	-	-	0
PCB 195	0.013	0 – 0.632	-	-	0
PCB 180	0.014	0 – 0.705	-	-	0
PCB 153	0.018	0 – 0.889	-	-	0
PCB 138/163/164 Mixture	0.019	0 – 0.56	-	-	0
PCB 12	0.031	0 – 0.496	-	-	-
Total PCBs	0.137	0 – 3.361	0	0	0
Pesticides (ng/g)					
2,4′-DDD	0	0 - 0	-	-	0
2,4′-DDE	0	0 - 0	0	0	0.03
2,4′-DDT	0	0 - 0	-	-	0
4,4′-DDD	0	0 - 0	-	-	0
4,4′-DDE	0	0 - 0	-	-	0
4,4′-DDT	0	0 - 0	-	-	0
Total DDT	0	0 – 0	0	0	0
Aldrin	0	0 - 0	-	-	0
Alpha-Chlordane	0	0 - 0	-	-	0
Chlorpyrifos	0	0 - 0	-	-	-
Dieldrin	0	0 - 0	-	-	3.58
Endosulfan I	0	0 - 0	-	-	0.87
Endosulfan II	0	0 - 0	-	-	0.95
Endosulfan Sulfate	0	0 - 0	-	-	-
Gamma-BHC (Lindane)	0	0 - 0	-	-	0.10
Heptachlor	0	0 - 0	-	-	0.76
Heptachlor Epoxide	0	0 - 0	-	-	0.97
Hexachlorobenzene	0	0 - 0	-	-	0.76
Mirex	0	0 - 0	-	-	0
Trans-Nonachlor	0	0 - 0	-	-	0

1 - Only PCBs with values > MDL listed here, see Table 1 for full list of congeners tested.

2 - Method Detection Limits (MDLs) were generally higher for the 2000-2004 NCA data as compared to the current study.

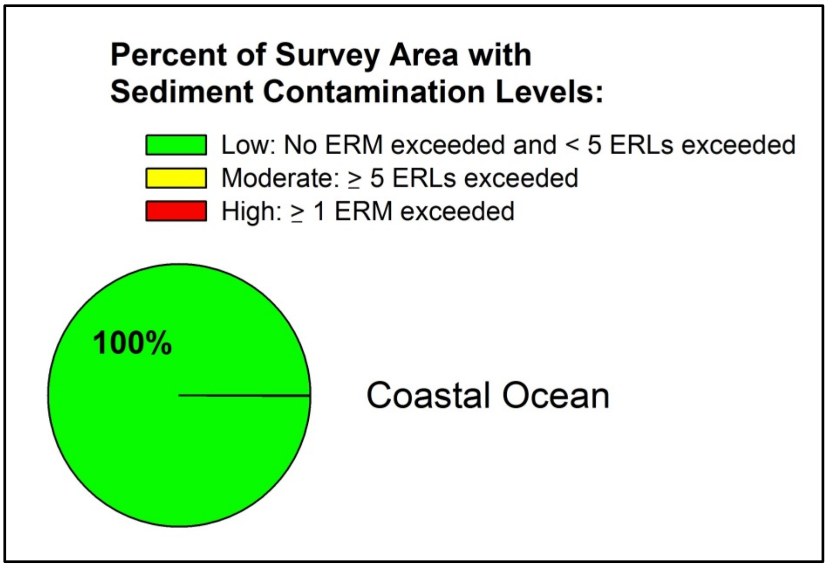

Figure 12. Percent area of South Florida shelf sediment contamination levels, expressed as number of ERL and ERM values exceeded, within specified ranges.

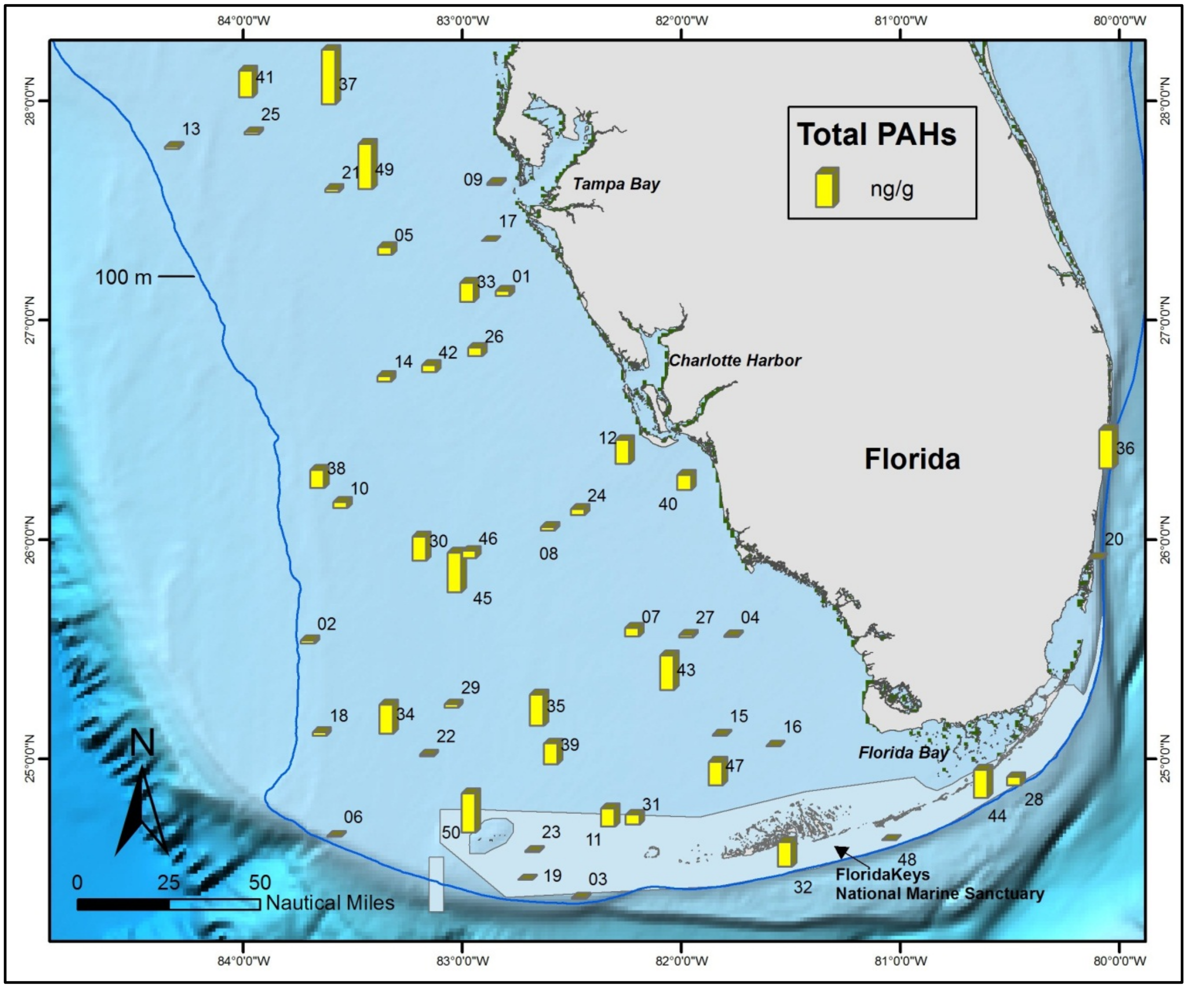

Figure 13. Spatial distribution of total PAH levels in South Florida shelf sediments.

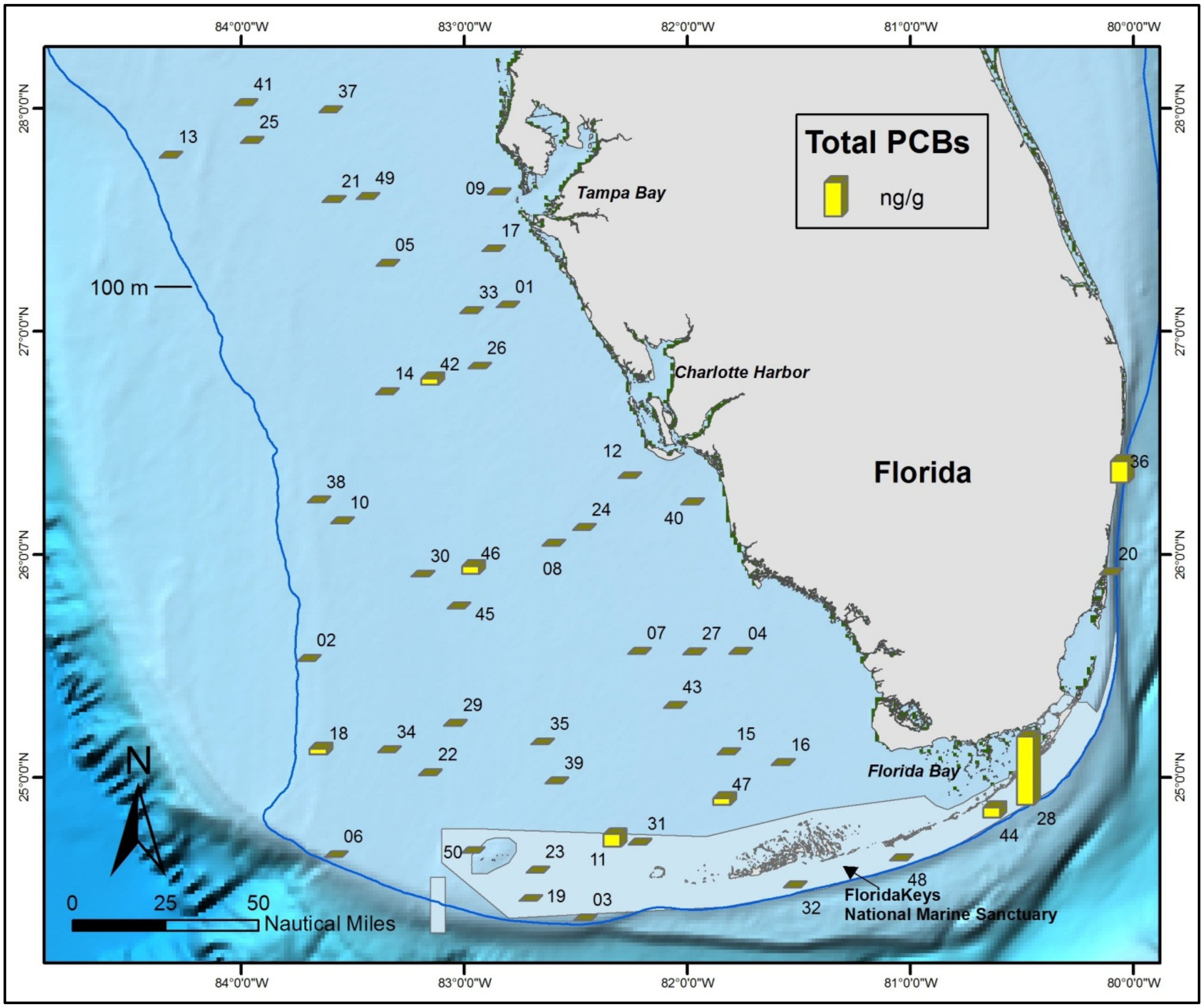

Figure 14. Spatial distribution of total PCB levels in South Florida shelf sediments.

3.2.3 Sediment Toxicity

There are currently no marine sediment toxicity tests that have been specifically developed for use on sediments from the continental shelf environment. The Microtox® solid-phase assay, an acute sediment toxicity test, has been used extensively for estuarine sediment toxicity testing (Ringwood et al. 1997, Muller et al. 2003, Macauley et al. 2010) and was determined to be a worthwhile toxicity test to evaluate during the current study. However, estuarine toxicity cut-points were not efficacious when applied to the offshore data (90% of the stations deemed toxic using Ringwood et al. 1997 cutpoints). No stations were identified in this study as having high levels of sediment contamination making it impossible to develop cut-points for this study. In addition, it was observed that sediments assayed had a distinct odor of biological decomposition which may have influenced the Microtox response.

Table 8. Results of Microtox solid-phase assay testing from 50 South Florida continental shelf stations.

Station	Mean Corr. EC50 (g/ml)	Mean Corr. EC50 (%)	% Silt/Clay
1	0.0021	0.2061	0.4700
2	0.0015	0.1504	0.1000
3	0.0020	0.2032	0.2700
4	0.0034	0.3363	0.0090
5	0.0013	0.1265	24.3100
6	0.0020	0.1961	0.2000
7	0.0012	0.1170	3.6200
8	0.0034	0.3394	0.1700
9	0.0093	0.9251	0.1000
10	0.0010	0.1030	29.5000
11	0.0002	0.0216	76.4800
12	0.0113	1.1343	0.0400
13	0.0012	0.1204	0.0300
14	0.0005	0.0452	53.3400
15	0.0014	0.1366	2.0200
16	0.0009	0.0911	5.1900
17	0.0041	0.4074	0.2400
18	0.0007	0.0682	25.1700
19	0.0052	0.5205	0.0300
20	0.0108	1.0795	0.0300
21	0.0009	0.0926	50.7500
22	0.0009	0.0920	19.4900
23	0.0013	0.1297	1.2100
24	0.0035	0.3468	1.0200
25	0.0024	0.2359	0.4900
26	0.0047	0.4749	0.0300
27	0.0010	0.0954	0.1100
28	0.0003	0.0314	28.4100
29	0.0011	0.1068	40.8400
30	0.0015	0.1532	21.8200

Station	Mean Corr. EC50 (g/ml)	Mean Corr. EC50 (%)	% Silt/Clay
31	0.0001	0.0120	76.2700
32	0.0001	0.0111	56.8600
33	0.0064	0.6440	0.2400
34	0.0009	0.0906	0.8100
35	0.0006	0.0638	38.7700
36	0.0015	0.1487	0.4600
37	0.0016	0.1601	31.7700
38	0.0010	0.0980	0.6500
39	0.0004	0.0361	79.3400
40	0.0008	0.0796	1.1000
41	0.0017	0.1721	1.0300
42	0.0019	0.1874	2.6100
43	0.0033	0.3289	0.8500
44	0.0003	0.0305	28.2800
45	0.0010	0.0968	0.0900
46	0.0015	0.1507	40.1300
47	0.0026	0.2590	0.7500
48	0.0004	0.0351	2.0100
49	0.0036	0.3581	0.0600
50	0.0004	0.0371	2.4500

3.3 Chemical Contaminants in Fish Tissues

Analysis of chemical contaminants in fish tissues was performed on homogenized fillets (including skin) from 60 samples of 11 fish species collected from 28 stations (see section 2.1 for additional information). Many of the measured contaminants in these samples were below corresponding method detection limits (MDL) (Table 9). However, 17 of the 22 inorganic trace metals that were measured, 20 of the 79 PCB congeners that were measured, three of the 26 measured PAHs, and 1 of the 19 measured pesticides were present at detectable levels.

USEPA (2000) developed human-health consumption limits for cancer and non-cancer (chronic systemic) health endpoints for a variety of contaminants (Table 4). Measured contaminant concentrations (Table 9) were found above the lower, but still below upper non-cancer consumption limits for mercury (n=22), inorganic arsenic (n=1), and PCBs (n=1). Additionally, 16 fish had measured contaminant levels above the upper non-cancer consumption limit for mercury. Figure 15 provides a summary of chemical contaminant concentrations (wet weight) measured in tissues of for the 60 fish analyzed summarized by species.

Of the 28 south Florida shelf stations where fish were collected and analyzed for chemical contaminants, 11 (39% of the 28 sites) had moderate levels of tissue contaminants, between lower and upper non-cancer effect thresholds, and ten (36% of the 28 sites) had measured fish with high levels of tissue contaminants above the upper threshold (Table 9). It is worthwhile to note that the fish with the highest tissue contaminant levels for both PCBs and PAHs (Figure 15), the blackline tilefish, was collected at station 28 (within the boundaries of the FKNMS) where the highest levels of PCBs were detected for this study. Given that tilefish are known for their construction of burrows in soft outer-continental shelf sediments and are generally considered non-migratory (Grimes and Turner 1999, Harris et al. 2003) these elevated tissue contaminants for this one tilefish may reflect local bioaccumulation.

Table 9. Summary of chemical contaminant concentrations (wet weight) measured in tissues of 60 fish (from 28 coastal ocean stations). Concentrations are compared to human health guidelines where available (from US EPA 2000, Table 2.7.3 here in). 'N/A' = no corresponding human health guideline available.

			No. of Fish Exceeding Non-Cancer Endpoints	
Analyte	Mean	Range	Lower	Upper
Trace Metals (µg g^{-1})				
Aluminum (Al)	3.1	0.3 - 32.5	-	-
Antimony (Sb)	0.0	0 - 0.1	-	-
Arsenic (As)	2.7	0.3 - 25.8	-	-
Inorganic Arsenic	0.1	0 – 0.5	1	0
Barium (Ba)	0.0	0 - 0.1	-	-
Beryllium (Be)	0.0	0 - 0	-	-
Cadmium (Cd)	0.0	0 - 0	0	0
Chromium (Cr)	0.3	0.2 - 0.6	-	-
Cobalt (Co)	0.0	0 - 0	-	-
Copper (Cu)	0.2	0.1 - 2.2	-	-
Iron (Fe)	1.5	0 - 4	-	-
Lead (Pb)	0.0	0 - 0.1	-	-
Lithium (Li)	0.0	0 - 0.1	-	-
Manganese (Mn)	0.1	0 - 0.3	-	-
Mercury (Hg)	0.2	0 - 0.7	22	16
Nickel (Ni)	0.0	0 - 0.1	-	-
Selenium (Se)	0.8	0.4 - 1.4	0	0
Silver (Ag)	0.0	0 - 0	-	-
Thallium (Tl)	0.0	0 - 0	-	-
Tin (Sn)	0.0	0 - 0	-	-
Uranium (U)	0.0	0 - 0	-	-
Vanadium (V)	8.6	0 - 223	-	-
Zinc (Zn)	4.6	2.9 - 7	-	-
PAHs (ng g^{-1})				
Total Detectable PAHs[1]	0.1	0 – 6.4	0	0
PCBs (ng g^{-1})				
Total Detectable PCBs	0.6	0 – 31.6	1	0
PBDEs (ng g^{-1})				
Total Detectable PBDEs	0	0 - 0	-	-
Pesticides (ng g^{-1})				
2,4'-DDD	0	0 - 0	-	-
2,4'-DDE	0	0 - 0	-	-
2,4'-DDT	0	0 - 0	-	-
4,4'-DDD	0	0 - 0	-	-
4,4'-DDE	0	0 - 0.9	-	-
4,4'-DDT	0	0 - 0	-	-
Aldrin	0	0 - 0	-	-
Chlordane-alpha	0	0 - 0	-	-
Chlorpyrifos	0	0 - 0	-	-
Dieldrin	0	0 - 0	0	0
Endosulfan Sulfate	0	0 - 0	-	-
Endosulfan-I	0	0 - 0	0	0
Endosulfan-II	0	0 - 0	-	-
Heptachlor	0	0 - 0	-	-
Heptachlor Epoxide	0	0 - 0	0	0

			No. of Fish Exceeding Non-Cancer Endpoints	
Analyte	Mean	Range	Lower	Upper
Hexachlorobenzene	0	0 - 0	0	0
Lindane	0	0 - 0	0	0
Mirex	0	0 - 0	0	0
trans-Nonachlor	0	0 - 0	-	-
Total Detectable DDTs	0	0 - 0.9	0	0

1. Cancer concentration range used, a non-cancer concentration range for PAHs does not exist.

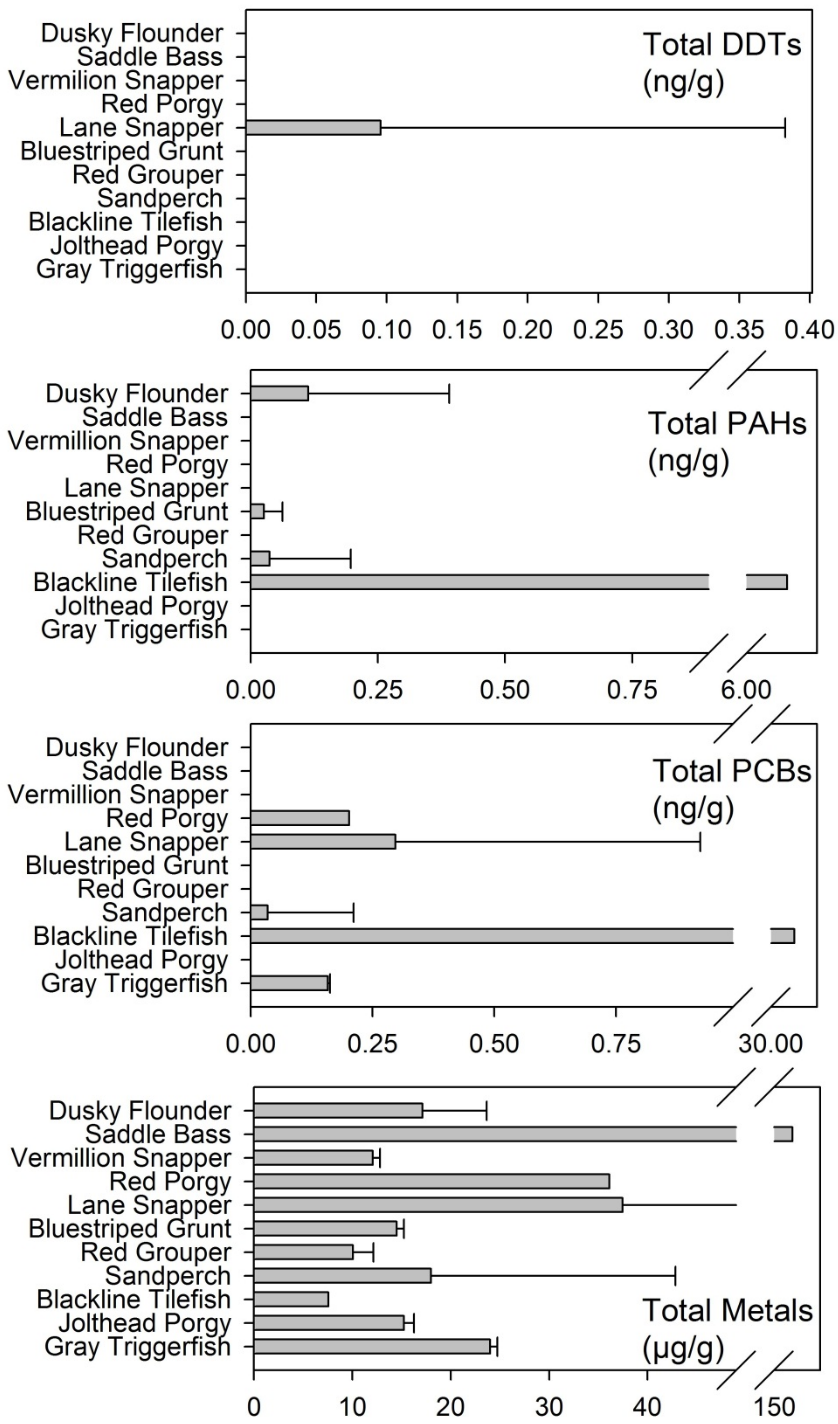

Figure 15. Summary of chemical contaminant concentrations (wet weight) measured in tissues of 60 fish (from 28 coastal ocean stations) summarized by species.

3.4 Status of Benthic Communities

Macrobenthic infauna (> 0.5 mm) were sampled from two separate grabs (0.04 m^2each) at all 50 stations, resulting in a total of 100 samples. The duplicate samples were averaged for the calculation of CDFs and other analysis purposes. The resulting data are used here to assess the status of benthic community characteristics (taxonomic composition, diversity, abundance and dominant species), biogeographic patterns, incidence of non-indigenous species, and potential linkages to ecosystem stressors.

3.4.1 Taxonomic Composition

A total of 646 taxa were identified across the South Florida continental shelf, of which 391 were identified to the species level. Polychaetes were the dominant taxa, both by percent abundance (59%) and percent taxa (54%; Figure 16, Table 10). Crustaceans were the second most dominant taxa, both by percent abundance (17%) and percent taxa (22%). Collectively, these two groups represented 76% of both the total faunal abundance and number of taxa throughout these offshore waters. Crustaceans were represented mostly by amphipods (78 identifiable taxa, 12% of the total number of taxa). Mollusca accounted for 14% of the taxa, and 10% of total faunal abundance. Echinoderms accounted for a small portion of total fauna by both percent abundance (1%) and percent taxa (1%).

The number of taxa found in these samples (646 including 391 identified to species) is higher in comparison to other east coast continental shelf regions sampled as part of the current offshore assessment series. Specifically, the South Atlantic Bight (SAB) had 462 taxa identified (313 to species; Cooksey et al. 2010a) and the Mid-Atlantic Bight (MAB) had only 381 taxa identified (215 to species; Balthis et al. 2009). This is a notable difference given that the size of the sampling frames for both of these other regions (110,941 km^2 for SAB and 103,198 km^2 for MAB) were larger compared to the South Florida shelf sampling area of 85,595 km^2. While the number of taxa varied among the regions, taxonomic composition was fairly similar in that all three regions were dominated by polychaetes, crustaceans, and molluscs.

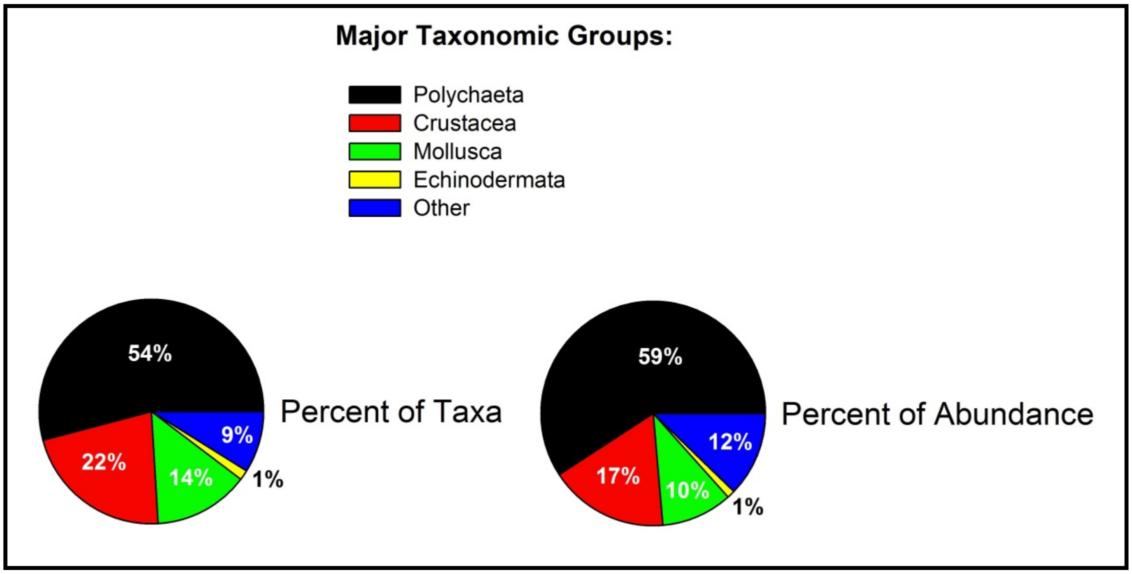

Figure 16. Relative percent composition of major taxonomic groups expressed as (A) percent of total taxa and (B) percent of abundance for South Florida continental shelf benthic communities.

Table 10. Summary of major taxonomic groups of benthic infauna and corresponding numbers of identifiable taxa in samples from South Florida shelf sites.

Taxonomic Group	Number identifiable taxa	% Total identifiable taxa
Phylum Porifera	1	0.15
Phylum Cnidaria		
Class Anthozoa	1	0.15
Phylum Nemertea	3	0.46
Phylum Sipuncula	8	1.24
Phylum Echiura	1	0.15
Phylum Annelida		
Class Polychaeta	257	39.78
Class Clitellata	2	0.31
Phylum Arthropoda		
Subphylum Crustacea		
Class Malacostraca		
Order Leptostraca	3	0.46
Order Stomatopoda	4	0.62
Order Decapoda	48	7.43
Order Mysidacea	5	0.77
Order Cumacea	16	2.48
Order Tanaidacea	17	2.63
Order Isopoda	25	3.87
Order Amphipoda	78	12.07
Phylum Mollusca		
Class Aplacophora	1	0.15
Class Polyplacophora	1	0.15
Class Gastropoda	57	8.82
Class Bivalvia	95	14.71
Class Scaphopoda	6	0.93
Phylum Phoronida	1	0.15
Phylum Ectoprocta	1	0.15
Phylum Brachiopoda	1	0.15
Phylum Echinodermata		
Class Asteroidea	1	0.15
Class Ophiuroidea	5	0.77
Class Echinoidea	2	0.31
Class Holothuroidea	4	0.62
Phylum Hemicordata	1	0.15
Phylum Chordata	1	0.15
Total	*646*	*100.00*

3.4.2 Abundance and Dominant Taxa

A total of 16,643 individual specimens were collected across the 50 coastal-ocean stations (100 0.04 m^{-2} grab samples). Densities ranged from 713 to 11,088 m^{-2} and averaged 4,335 m^{-2} (Figure 17, Table 11, Appendix E). Thus there were no offshore samples that were devoid of benthic fauna. Spatially, 10% of the shelf area had densities > 8,292 m^{-2} and 50% of the shelf area had densities > 4,208 m^{-2} (Table 11). The average densities reported from this survey are slightly higher than those reported for the SAB (3,118 m^{-2}, Cooksey et al. 2010a) and the West Coast (3,788 m^{-2}, Nelson et al. 2008), but lower than those reported for the MAB (6,067 m^{-2}, Balthis et al. 2009).

The 50 most abundant taxa throughout the region are listed in Table 12. The 10 most abundant taxa on this list include the polychaetes *Prionospio cristata*, *Goniadides carolinae*, *Fabricinuda trilobata*, *Armandia maculata*, *Chone* spp., *Magelona pettiboneae, Prionospio* spp. and *Paleanotus* spp.; tubificid oligochaetes; and the crustacean *Leptochelia* spp.. The tubificids were the most abundant taxon overall with a mean density of 156 m^{-2}, but were closely followed by the polychaete *Prionospio cristata* with a mean density of 151 m^{-2}. The three taxa with the highest frequency of occurrence were the Tubificidae, and the polychaetes *F. trilobata* and *A. maculata*.

In 1999 and 2000, a total of 177 stations (510 grabs) distributed across the South Florida continental shelf were sampled by NOAA for benthic community composition (unpublished data available through www.nbi.noaa.gov). These stations were selected with a non-probabilistic sampling design, cover a slightly different geographic area than the current survey, and lack information on sediment characteristics and other environmental controlling factors; however, they were collected with a Young Grab (0.04 m^{-2}) and, therefore, some comparisons can be made with the present offshore study. Densities in this 1999-2000 study ranged from 1,142 to 17,788 m^{-2} and averaged 5,351 m^{-2}. These numbers are similar to the densities observed in 2007, though slightly higher. There is also some overlap in the dominant taxa. Specifically, there are four taxa (tubificid oligochaetes and the polychaetes *Prionospio* spp., *Armandia maculata* and *Magelona pettiboneae)* which are among the top 10 dominant taxa for both studies.

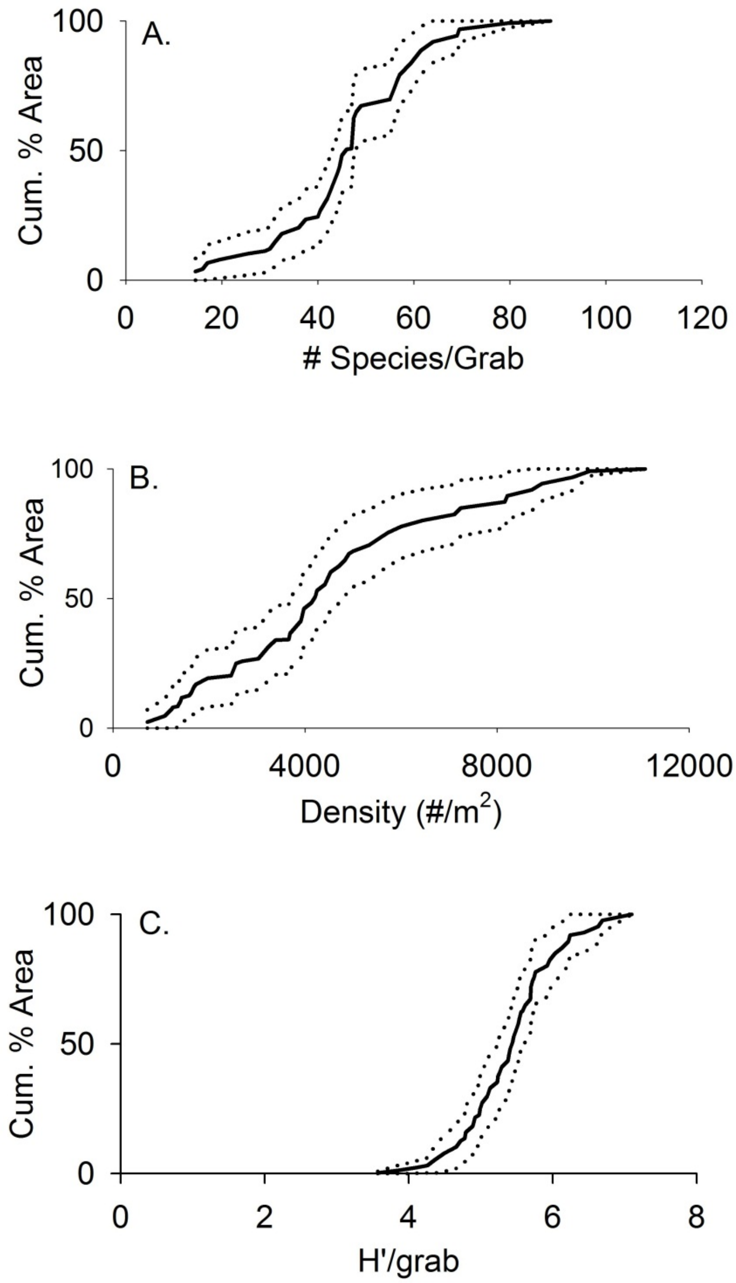

Figure 17. Percent area (solid lines) and 95% Confidence Intervals (dotted lines) of South Florida coastal ocean benthic infaunal species richness (A), density (B), and H′ diversity (C).

Table 11. Mean, range and selected properties of key benthic variables representing from 50 South Florida coastal ocean sites (2 replicate 0.04-m^2 grabs per site).

	Overall Mean	Overall Range	Areal-Based Percentiles[1]: CDF 10^{th} %	CDF 50^{th} %	CDF 90^{th} %	Frequency-Based Percentiles[2] 10^{th}	25^{th}	50^{th}	75^{th}	90^{th}
# Taxa per grab	45	15-89	25	45	63	19	32	44	55	62
Density (#/m^2)	4335	713-11088	1400	4208	8292	1288	2413	3794	5325	8269
H′ per grab	5.4	1.36-7.1	4.6	5.4	6.2	4.4	4.9	5.3	5.6	6.1

[1] Value of response variable corresponding to the designated cumulative % area point along the y-axis of the CDF graph.
[2] Corresponding lower 10^{th} percentile, lower quartile, median, upper quartile, and upper 10^{th} percentile of all values for each of the 3 benthic variables.

Table 12. Fifty most abundant benthic taxa from 50 South Florida coastal ocean sites (2 replicate 0.04-m^2 grabs per site). Classification: Native = native species; Indeter = indeterminate taxon (not identified to a level that would allow determination of origin).

Taxa Name	Taxon	Classification	Mean Density	% Frequency of Occurrence
Tubificidae	Other	Indeter	156	71
Prionospio cristata	Polychaeta	Native	151	46
Goniadides carolinae	Polychaeta	Native	96	27
Fabricinuda trilobata	Polychaeta	Native	94	62
Armandia maculata	Polychaeta	Native	82	63
Chone spp.	Polychaeta	Indeter	76	55
Magelona pettiboneae	Polychaeta	Native	72	41
Prionospio spp.	Polychaeta	Indeter	72	42
Leptochelia spp.	Crustacea	Indeter	63	41
Paleanotus spp.	Polychaeta	Native	60	42
Litocorsa spp.	Polychaeta	Native	53	44
Nemertea	Other	Indeter	52	39
Branchiostoma spp.	Other	Indeter	51	32
Exogone lourei	Polychaeta	Native	47	26
Paraprionospio pinnata	Polychaeta	Native	45	29
Ceratocephale oculata	Polychaeta	Native	38	40
Synelmis spp.	Polychaeta	Native	37	35
Tellina spp.	Mollusca	Indeter	35	30
Mediomastus spp.	Polychaeta	Indeter	34	39
Branchiomma nigromaculata	Polychaeta	Native	33	7
Xenanthura brevitelson	Crustacea	Native	32	52
Maldanidae	Polychaeta	Indeter	30	53
Lumbrineris verrilli	Polychaeta	Native	29	46
Sigambra tentaculata	Polychaeta	Native	29	30
Maera caroliniana	Crustacea	Native	28	9
Tubulanus spp.	Other	Indeter	27	29
Sphaerosyllis piriferopsis	Polychaeta	Native	27	32
Sipuncula	Other	Indeter	24	32
Haplosyllis spongicola	Polychaeta	Native	24	13
Cumella spp.	Crustacea	Indeter	23	35
Pisione spp.	Polychaeta	Native	22	18
Ampharetidae	Polychaeta	Indeter	22	32
Cupuladria	Other	Indeter	22	29
Psammokalliapseudes granulosus	Crustacea	Native	22	18
Ancistrosyllis hartmanae	Polychaeta	Native	21	13
Lucinidae	Mollusca	Indeter	20	16
Galathowenia oculata	Polychaeta	Native	20	36
Eunice unifrons	Polychaeta	Native	19	25
Euchone incolor	Polychaeta	Native	19	20

Taxa Name	Taxon	Classification	Mean Density	% Frequency of Occurrence
Gammaropsis spp.	Crustacea	Indeter	19	20
Codakia pectinella	Mollusca	Native	18	11
Heteropodarke formalis	Polychaeta	Native	18	18
Goniadella spp.	Polychaeta	Native	17	19
Terebellidae	Polychaeta	Indeter	17	26
Lineidae	Other	Indeter	17	28
Chevalia carpenteri	Crustacea	Native	16	19
Enchytraeidae	Other	Indeter	16	20
Protodorvillea kefersteini	Polychaeta	Native	16	20
Ophiuroidea	Echinodermata	Indeter	16	22
Spio pettiboneae	Polychaeta	Native	15	23

3.4.3 Diversity

Species richness, expressed as the number of taxa present in a 0.04 m^2 grab, was relatively high in these South Florida shelf assemblages. A total of 646 taxa were identified region-wide from the 50 benthic grabs. Species richness ranged from 15 to 89 taxa $grab^{-1}$ and averaged 45 taxa $grab^{-1}$ (Figure 17, Table 11, Appendix E). Approximately 50% of the offshore survey area had > 45 taxa $grab^{-1}$ and 10% of the area had > 63 taxa $grab^{-1}$.

The high species richness, plus an even distribution of species abundance within stations, resulted in high values of the diversity index H′ (log base 2) for this shelf region. Diversity values ranged from 1.36 to 7.1 $grab^{-1}$ and averaged 5.4 $grab^{-1}$ (Figure 17, Table 11, Appendix E). Approximately 50% of the offshore survey area had H′ > 5.4 $grab^{-1}$ and 10% of the area had H′ > 6.2 $grab^{-1}$.

Benthic species richness and H′ diversity were higher for the South Florida shelf then for either the MAB or SAB studies (Balthis et al. 2009 and Cooksey et al. 2010a, respectively). Species richness was lower for the South Florida shelf as compared to the West Coast shelf (79 taxa $grab^{-1}$). However, diversity was very similar for the South Florida shelf and the West Coast shelf (5.01 $grab^{-1}$; Nelson et al. 2008). For the 1999-2000 unpublished NOAA data, species richness ranged from 17 to 116 taxa $grab^{-1}$ and averaged 68 taxa $grab^{-1}$, while diversity ranged from 2.7 to 6.2 $grab^{-1}$ and averaged 5.22 $grab^{-1}$. These 1999-2000 data are more similar to the West Coast shelf data than to the current 2007 survey, where both richness and diversity are slightly lower.

3.4.4 Cluster Analysis

Spatial patterns in the distribution of benthic infauna among stations were examined by hierarchical cluster analysis on double-square-root transformed data using PRIMER analytical software (Clarke and Gorley, 2001). Group-average sorting (= unweighted pair-group method; Sneath and Sokal, 1973) was used as the clustering method and Bray-Curtis dissimilarity (Bray and Curtis, 1957) was used as the resemblance measure. Results were expressed as a dendrogram in which samples were ordered into groups of increasing similarity based on resemblances of component-species abundances. Canonical discriminant analysis, performed with the CANDISC procedure in SAS (2002), also was used to determine whether the separation of the cluster groups could be explained by other measured abiotic environmental factors (*sensu* Green and Vascotto, 1978). Abiotic variables that were considered included depth, percent silt-clay, TOC, dissolved oxygen, salinity, chlorophyll *a*, TSS, latitude and longitude. The analysis sought to derive a reduced set of discriminant (canonical) functions that best described the separation of the pre-declared station groups based on data represented by the different abiotic environmental variables. Total structure coefficients (TSC), which are the correlations between the original variables and the discriminant scores on each function, provided a measure of the relative contribution of each variable to group separation.

Results of the cluster analysis are presented as a dendrogram in Figure 18. Application of a Bray-Curtis dissimilarity value of 0.5 revealed two major site groups, A and B, consisting of 36 of the 50 stations (Figures 18 and 19). The remaining 14 stations formed 11smaller branches, consisting of either a single station (O1 –O8) or two stations (O9-O11). Cluster group B was further divided into two subgroups (B1 and B2) at a dissimilarity level of 0.45. This resulted in a total of 14 separate site groups (Figure 18). Group A generally encompasses mid-shelf stations, while group B1 is dominated by outer-shelf stations and group B2 is dominated by inner-shelf stations. The 11 smaller site groups with O designations were scattered throughout the sampling region.

Results of the canonical discriminant analysis showed that the first canonical function was significant (CAN 1: $p < 0.0001$, df = 117) and accounted for 46% of the among-group variation in abiotic variables. The second canonical function was significant at an alpha level of 0.001 (CAN 2: $p = 0.001$, df = 3) and accounted for an additional 22% of the among-group variation in abiotic variables. TSCs for CAN 1 (Table 13) reveal that the strongest correlation on this function is with percent silt-clay, a well-known driver of benthic communities. TSCs for CAN2 reveal the strongest correlation is with chlorophyll *a* and TSS, both of which will generally decrease with distance from shore.

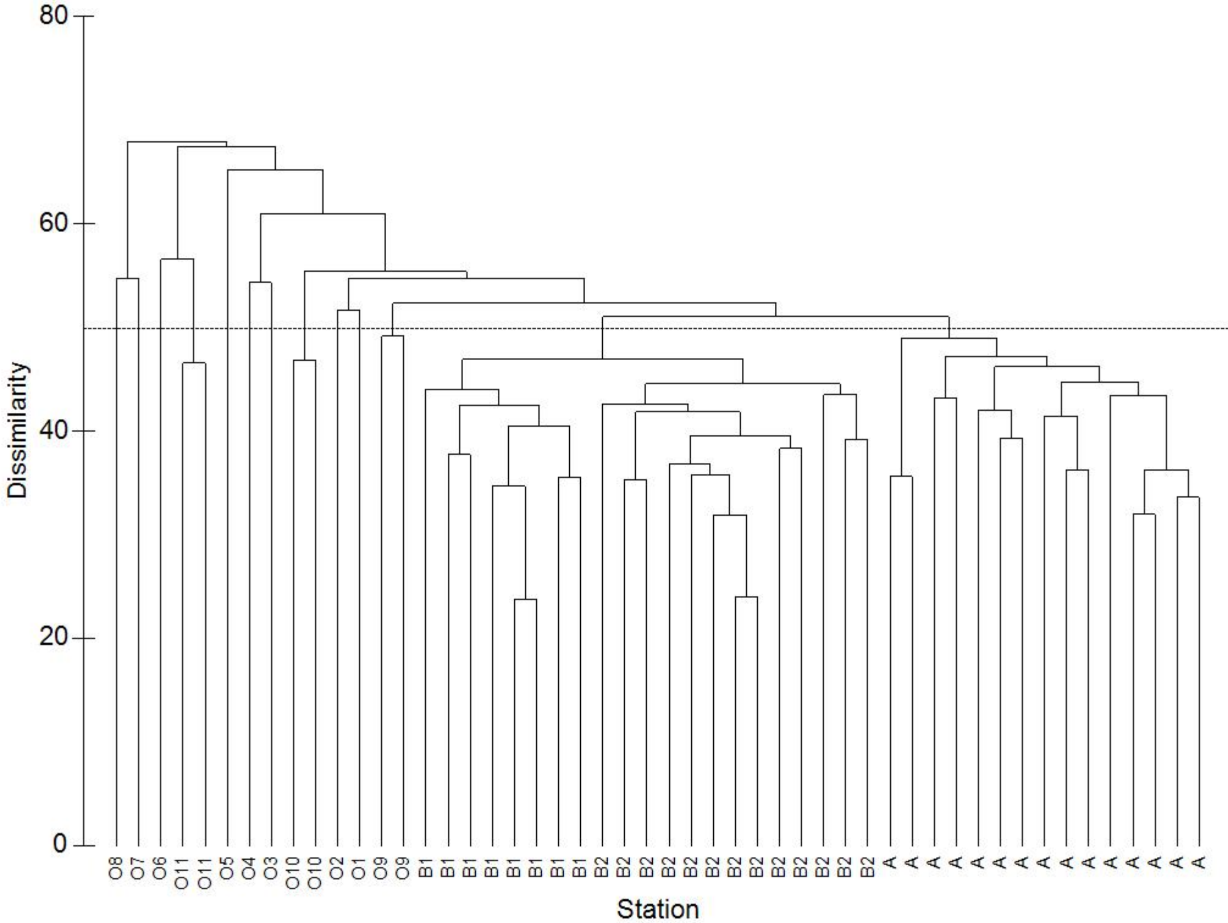

Figure 18. Dendrogram resulting from clustering of benthic samples using group-average sorting and Bray-Curtis dissimilarity. A dissimilarity level of 0.5 (horizontal line) was used to define the two major site groups, A and B, plus O1-O11. Cluster group B was further divided into two subgroups (B1 and B2) at a dissimilarity level of 0.45.

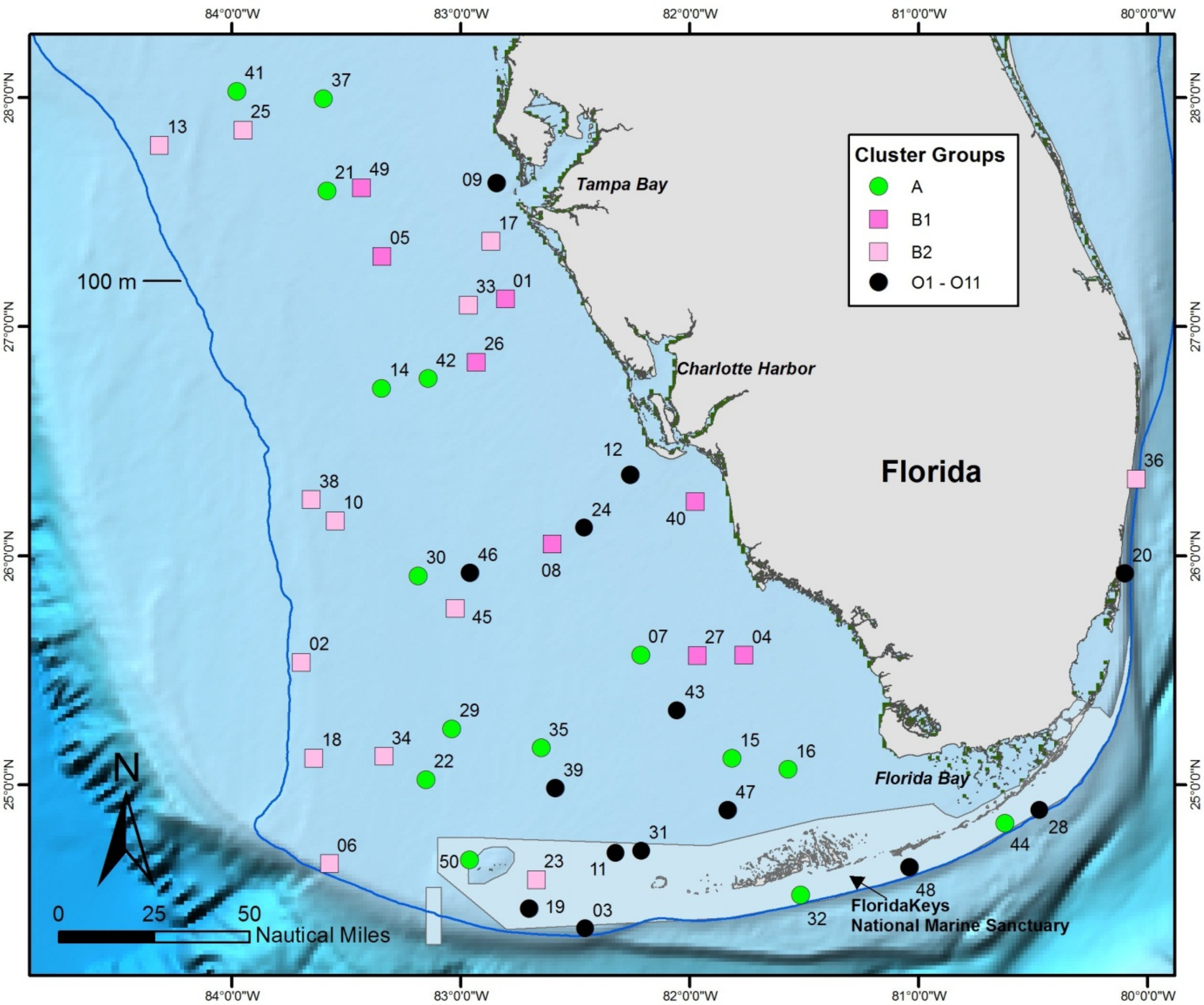

Figure 19. Map showing cluster groups for 50 South Florida continental shelf stations.

Table 13. Total structure coefficients (TSC) from canonical discriminant analysis. Can1= first canonical variable (46% if variability); Can2=second canonical variable (22% of variability).

Abiotic Variable	Can1	Can2
Depth	-0.059251	-0.571556
% Silt-Clay	<u>0.672908</u>	0.414865
TOC	0.089224	-0.042192
Latitude	-0.347412	0.030231
Longitude	0.108247	0.162208
Salinity	0.486244	-0.101013
DO	-0.056703	0.139629
Chlorophyll a	-0.213435	<u>0.695819</u>
TSS	-0.342826	<u>0.678554</u>

3.4.5 Non-Indigenous Species

The scale of the current survey provides a unique opportunity to examine the benthic macroinfauna data for the occurrence of non-indigenous species throughout the South Florida continental shelf and Florida Keys National Marine Sanctuary. Overall, there were a total of 13,477 individual specimens distributed among 646 taxa identified from 100 grabs. Of those 646 taxa, 391 were identified to the species level. Of the 391 taxa, none were identified as non-indigenous based on a comparison with the USGS Non-indigenous Aquatic Species database (http://nas.er.usgs.gov). The South Florida shelf benthos appears to be less invaded than some other coastal regions such as the Pacific Coast, where non-indigenous species are common in estuaries and occur offshore as well, though in more limited numbers (e.g., 1.2% of the identified species in a survey of the western U.S. continental shelf; Nelson et al. 2008), but similar to the MAB and SAB where no non-indigenous species were found (Balthis et al. 2009 and Cooksey et al. 2010a respectively).

3.5 Florida Keys National Marine Sanctuary

Florida Keys National Marine Sanctuary (FKNMS) holds a prominent place within the South Florida Continental shelf region. FKNMS surrounds the Florida Keys and covers 9,933 km^2 of productive and unique marine habitats including mangrove, seagrass, hardbottom and coral reef habitats in both coastal and oceanic water (Office of National Marine Sanctuaries 2011). The current survey did not focus on FKNMS exclusively, but did include ten stations within the boundaries of the sanctuary that provide a basis for comparing its condition relative to the surrounding shelf environment. In general, conditions within the sanctuary were remarkably similar to conditions across the rest of the South Florida shelf (Figure 20). Although mERMq values were similarly low at FKNMS and non-sanctuary stations (mERMq=0.011), it is worth noting that there were detectable levels of PCBs and PAHs within as well as outside the sanctuary boundaries (Figures 13, 14). In fact, the highest level of PCBs in sediment across the region occurred within the sanctuary at station 28. There were no identifiable man-made point sources for PCBs or PAHs located near station 28 (S. Donahue, personnel communication, November 6, 2012). These data indicate that it would be worthwhile to complete a dedicated site-intensive survey of condition within FKNMS as has been done previously for the Gray’s Reef National Marine Sanctuary (Cooksey et al. 2004, Balthis et al. 2007) and Stellwagon Bank National Marine Sanctuary (Balthis et al. 2011).

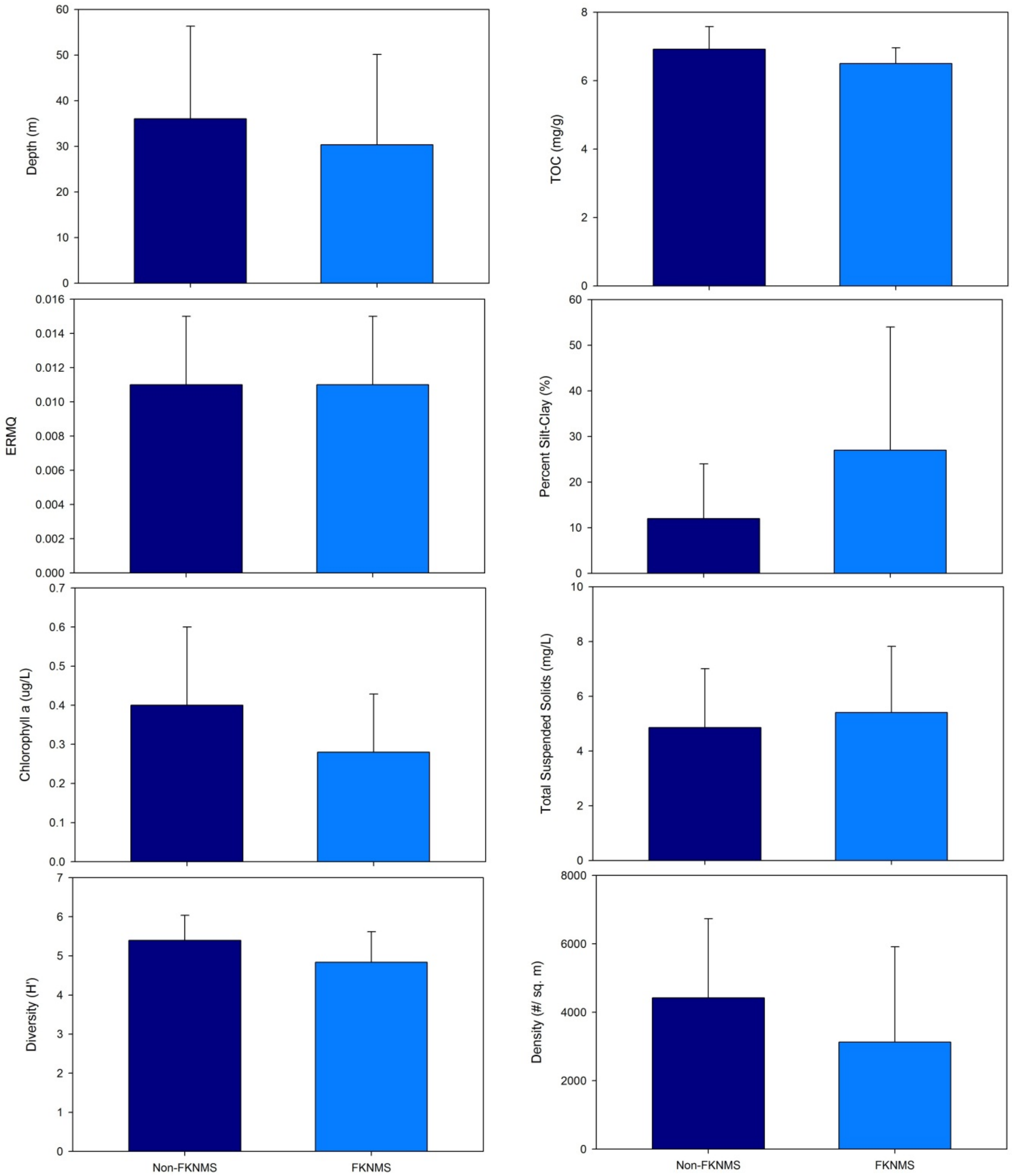

Figure 20. Comparison of select abiotic and biotic variables (mean +1 SD) within the Florida Keys National Marine Sanctuary (n=10) and the remainder of the South Florida continental shelf (n=40).

3.6 Potential Linkage of Biological Condition to Stressor Impacts

Multi-metric benthic indices are an important tool for detecting signals of degraded sediment quality and have been developed for a variety of estuarine applications (Engle et al. 1994, Van Dolah et al. 1999, Llanso et al. 2002a, 2002b). An important feature of a multi-metric benthic index is the ability to combine multiple benthic community attributes (e.g., numbers of species, diversity, abundance, relative proportions of groups of species) into a single measure that maximizes the ability to distinguish between degraded versus non-degraded benthic condition while taking into account biological variability associated with natural controlling factors (e.g. latitude, salinity, sediment particle size). No such multi-metric benthic index exists for the South Florida continental shelf. In the absence of a benthic index, potential stressor impacts in offshore waters were assessed by looking for obvious linkages between reduced values of key benthic characteristics (diversity, richness, density) and synoptically measured indicators of poor sediment or water quality. To be consistent with related offshore studies where multi-metric benthic indices have been lacking (Nelson et al. 2008, Balthis et al. 2009, Cooksey et al. 2010), low values of benthic attributes were defined as the lower 10th percentile of observed values and evidence of poor sediment or water quality was defined using the following guidelines: ≥ 1 chemical in excess of ERMs, TOC > 50 mg g^{-1}, or DO in near-bottom water < 2 mg L^{-1}. Because none of the offshore stations were rated as having poor sediment or water quality based on these latter guidelines, there was little evidence to suggest linkages between impaired benthic condition and measured stressors (Appendix E). Thus, lower values of key biological attributes (numbers of taxa, diversity, and abundance), defined as the lower 10th percentile of observed values, appeared to represent parts of a normal reference range controlled by natural factors.

Results of this study show that natural resources throughout the South Florida continental shelf are generally in good condition with respect to many of the measured ecological indicators. However, this assessment also suggests some areas of concern. For example, there were low but detectable levels of PAHs and PCBs in sediments throughout the region and elevated levels of tissue contaminants in many of the fish examined. It would be prudent to use such information as an early-warning signal and justification for implementing effective coastal management practices in order to prevent potential growth of future environmental risks from increasing human activities in the region. The South Florida continental shelf provides many important ecosystem goods and services across a variety of categories: supporting (e.g., nutrient cycling, reservoirs of biodiversity, habitat for protected species and other natural populations), provisional (e.g., mineral extraction, alternative energy, food, corridors for maritime trade), regulating (e.g., pollutant sequestering, hurricane buffering), and cultural (e.g., swimmable and fishable waters for recreation; protected areas for research, education, and nature conservation). As development continues throughout Florida and the Gulf of Mexico, the coastal-ocean environments should be monitored if we are to better understand and manage these important resources and the functions they provide.

4.0 Acknowledgments

This study was made possible through the coordination of resources and staff under a General Collaborative Agreement (MOA 2005-003/6764) between the NOAA National Ocean Service's (NOS) National Centers for Coastal Ocean Science (NCCOS) and the EPA Office of Research and Development (ORD)/National Health and Environmental Effects Research Laboratory (NHEERL). Funding was provided primarily by the NOAA/NCCOS Center for Coastal Environmental Health and Biomolecular Research (CCEHBR) to support field work and processing of samples. Field work was conducted on the NOAA Ship Nancy Foster Cruise NF-07-08-NCCOS by scientists from NOAA/NCCOS, NOAA/NODC/National Coastal Data Development Center, USGS/National Wetlands Research Center/Gulf Breeze Project Office, South Carolina Department of Natural Resources/Marine Resources Research Institute and Florida Fish and Wildlife Research Institute. Two institutions outside of NCCOS participated in the processing of samples. These are Barry Vittor and Associates (Mobile, AL) for the analysis of benthic samples and NOAA, Oceanic and Atmospheric Research (OAR), Atlantic Oceanographic and Meteorological Laboratory (AOML) (Miami, FL) for nutrients and chlorophyll in water samples. All collections inside FKNMS were conducted under National Marine Sanctuary Permit FKNMS-2007-024. We thank Scott Donahue (FKNMS), Jim Harvey (EPA) and Marie Delarenoz (NCCOS) who generously contributed their time and expertise in reviewing this report.

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Appendix A. Locations, depths, and sediment characteristics of 50 South Florida coastal ocean sites sampled May 2007.

Station	Latitude (DD)	Longitude (DD)	Depth (m)	TOC (mg/g)	Gravel (%)	Sand (%)	Silt-Clay (%)
01	27.12087	-82.80398	20	4.5	3.8	95.6	0.5
02	25.53472	-83.69460	80	5.8	5.5	91.2	0.1
03	24.37048	-82.45630	26	5.9	1.8	96.7	0.3
04	25.56550	-81.76083	11	3.8	16.1	82.6	0
05	27.30783	-83.34252	34	5.8	14.5	61.2	24.3
06	24.65420	-83.57270	60	5.9	8.1	91.5	0.2
07	25.56667	-82.21350	24	5.7	0	92.9	3.6
08	26.05083	-82.59855	29	5.3	2.1	97.7	0.2
09	27.62707	-82.84247	7	5.2	4.5	95.3	0.1
10	26.15245	-83.54550	62	5.8	0.2	70.3	29.5
11	24.70000	-82.32333	17	6.1	0	23.5	76.5
12	26.35412	-82.25788	10	5.1	1	99	0
13	27.79247	-84.31427	66	6.3	2.2	97.6	0
14	26.73098	-83.34502	49	4.5	0.5	46.1	53.3
15	25.11470	-81.81415	14	6.7	0.1	96.6	2
16	25.06673	-81.56967	8	6.2	6.8	85.7	5.2
17	27.37243	-82.86783	13	4.9	9.7	89.2	0.2
18	25.11575	-83.64058	73	6.4	17.2	57.7	25.2
19	24.45742	-82.70073	19	6.1	0.2	98	0
20	25.92218	-80.09922	11	6	4.9	95	0
21	27.59380	-83.58323	41	5.4	0.3	49	50.8
22	25.02147	-83.15103	57	5.4	3.5	77	19.5
23	24.58415	-82.66878	21	5.7	12.4	86.1	1.2
24	26.12163	-82.46075	22	5.2	1.4	96.3	1
25	27.85867	-83.94977	48	5.7	8.3	86.6	0.5
26	26.84597	-82.93068	32	5.4	2.2	97.2	0
27	25.56405	-81.96623	16	5.8	9.1	90.7	0.1
28	24.88888	-80.47110	83	6.4	2	69.6	28.4
29	25.24372	-83.03883	55	6.1	1.5	57.7	40.8
30	25.91242	-83.18495	53	5.9	0.6	77.6	21.8
31	24.71000	-82.21083	18	5.5	0	23.7	76.3
32	24.51718	-81.51578	26	6.8	0.5	42.7	56.9
33	27.09465	-82.96653	23	5.1	34.1	65.5	0.2
34	25.12393	-83.33477	61	5.4	7.9	90.8	0.8
35	25.16000	-82.64817	37	5.3	12.1	49.2	38.8
36	26.33537	-80.04880	52	4.6	43.5	54.2	0.5
37	27.99618	-83.59837	31	4.7	0.1	68.2	31.8
38	26.24477	-83.65077	63	6.6	7.6	91.2	0.7
39	24.98422	-82.58475	33	6	0	20.6	79.3
40	26.23585	-81.97513	9	4.2	39.1	59	1.1
41	28.02810	-83.97695	46	5.1	7.7	87.6	1
42	26.77330	-83.14097	41	5.5	0.8	94.7	2.6
43	25.32350	-82.05418	18	6.3	1.1	97.6	0.9
44	24.83147	-80.62205	39	6.8	6.4	65.3	28.3
45	25.76993	-83.02347	49	5.1	10.3	88.8	0.1
46	25.92475	-82.95797	43	4.7	0.3	59.6	40.1
47	24.88825	-81.83235	13	6.3	2.6	95.6	0.8
48	24.63923	-81.03970	23	5.9	0.1	95.5	2
49	27.60757	-83.43165	35	5.5	2.2	95.1	0.1
50	24.67230	-82.96003	32	5.4	1.3	93.5	2.5

Appendix B. Near-surface water characteristics of 50 South Florida coastal ocean sites sampled May 2007.

Station	Temp. °C	Salinity (psu)	DO (mg/L)	pH	DIN (mg/L)	DIP (mg/L)	N/P	Chlorophyll a (µg/L)	Phaeophytin (µg/L)	Silicate (µg/L)	TSS (mg/L)
01	24.3	36.1	6.5	8.0	0.005	0.002	5.00	0.18	0.06	0.0	2.7
02	26.9	36.4	5.9	7.9	0.004	0.000	-	0.04	0.01	15.7	4.1
03	26.9	36.4	5.9	8.0	0.006	0.031	0.36	0.12	0.05	42.0	3.2
04	26.9	36.7	6.3	7.9	0.004	0.000	-	0.99	0.28	27.7	3.3
05	24.4	36.7	6.5	8.0	0.008	0.019	0.75	0.10	0.05	0.0	3.7
06	26.7	35.5	7.2	8.0	0.002	0.000	-	0.08	0.04	10.1	6.8
07	25.8	37.0	6.1	8.0	0.002	0.000	-	0.27	0.08	21.3	3.7
08	25.8	36.9	6.3	7.9	0.003	0.005	1.40	0.18	0.06	33.6	3.4
09	25.3	35.7	6.7	-	0.004	0.021	0.36	0.74	0.26	98.0	9.8
10	25.4	36.5	6.2	8.0	0.036	0.003	26.33	0.08	0.03	20.4	3.3
11	27.2	36.6	5.9	7.9	0.004	0.002	4.00	0.37	0.11	84.0	5.7
12	25.7	36.3	6.3	7.9	0.003	0.005	1.40	0.28	0.11	0.0	2.2
13	24.9	36.4	6.7	10.2	0.002	0.004	1.00	0.10	0.05	0.0	4.1
14	25.4	36.5	6.3	8.0	0.004	0.003	2.67	0.07	0.03	4.5	2.7
15	26.8	36.9	6.1	7.9	0.005	0.002	5.50	0.29	0.17	0.0	5.6
16	27.3	36.5	6.0	8.0	0.002	0.002	2.00	0.34	0.17	53.2	6.3
17	24.7	36.1	6.3	8.0	0.005	0.004	2.75	0.17	0.06	0.0	8.9
18	26.2	36.4	6.0	7.9	0.005	0.000	-	0.06	0.03	26.0	4.6
19	27.2	36.4	6.0	7.9	0.003	0.000	-	0.14	0.04	18.2	3.2
20	26.5	36.3	5.9	8.0	-	-	-	0.57	0.18	-	3.6
21	24.9	36.5	6.4	8.0	0.002	0.001	5.00	0.09	0.03	0.0	5.5
22	25.6	36.5	6.1	7.9	0.003	0.000	-	0.07	0.03	12.0	3.0
23	27.1	36.4	5.9	7.9	0.005	0.000	-	0.16	0.05	36.4	2.1
24	25.6	36.7	6.2	7.9	0.005	0.000	-	0.28	0.11	23.8	3.5
25	24.4	36.4	6.8	10.4	0.003	0.001	7.00	0.08	0.03	0.0	3.7
26	25.0	36.7	6.2	8.0	0.003	0.000	-	0.09	0.03	2.5	5.9
27	26.1	36.8	6.0	7.9	0.002	0.000	-	0.23	0.08	10.4	3.4
28	27.2	36.3	6.0	8.0	0.005	0.000	-	0.08	0.03	12.0	2.9
29	25.5	36.5	6.3	7.9	0.004	0.000	-	0.07	0.03	7.3	6.3
30	26.7	36.4	6.0	8.0	0.000	0.000	-	0.08	0.03	8.1	2.4
31	27.4	36.8	6.0	8.0	0.000	0.000	-	0.68	0.16	4.2	6.8
32	27.3	36.3	5.9	7.9	0.005	0.000	-	0.19	0.08	42.0	6.1
33	24.5	36.3	6.5	8.0	0.004	0.000	-	0.16	0.06	0.0	2.5
34	25.8	36.5	6.2	8.0	0.005	-	-	0.06	0.03	0.0	7.3
35	26.8	36.4	6.0	8.0	0.006	0.000	-	0.06	0.03	0.0	3.6

Station	Temp. °C	Salinity (psu)	DO (mg/L)	pH	DIN (mg/L)	DIP (mg/L)	N/P	Chlorophyll a (µg/L)	Phaeophytin (µg/L)	Silicate (µg/L)	TSS (mg/L)
36	27.1	36.3	5.9	8.0	-	-	-	0.17	0.07	-	2.9
37	24.3	36.5	6.8	9.6	0.004	0.000	-	0.06	0.03	0.0	5.3
38	25.2	36.5	6.2	8.0	0.007	0.000	-	0.07	0.03	0.0	2.8
39	26.6	36.4	6.0	8.0	0.002	0.000	-	0.08	0.03	0.0	3.0
40	25.8	36.4	6.1	7.9	0.003	0.003	2.00	0.56	0.18	0.0	4.9
41	23.8	36.5	6.8	10.8	0.001	0.000	-	0.10	0.04	0.0	8.0
42	25.7	36.6	6.3	8.0	0.004	0.000	-	0.07	0.03	6.7	3.3
43	26.4	37.0	6.0	7.9	0.010	0.000	-	0.30	0.09	11.2	3.1
44	27.3	36.2	5.9	8.0	0.007	0.000	-	0.20	0.07	25.2	3.1
45	26.9	36.4	6.1	8.0	0.006	0.000	-	0.06	0.02	25.2	5.2
46	26.3	36.5	6.1	8.0	0.004	0.001	8.00	0.06	0.02	10.6	2.1
47	27.0	36.9	6.2	8.0	0.005	0.000	-	0.45	0.21	0.0	9.3
48	27.1	36.3	5.8	7.9	0.005	0.000	-	0.16	0.07	33.6	4.5
49	24.7	36.3	6.4	5.9	0.005	0.001	11.00	0.15	0.02	0.0	2.7
50	27.2	36.2	6.0	7.9	0.004	0.000	-	0.19	0.06	61.6	3.0

Appendix C. Near-bottom water characteristics of 50 South Florida coastal ocean sites sampled May 2007.

Station	Temp. °C	Salinity (psu)	DO (mg/L)	pH	DIN (mg/L)	DIP (mg/L)	N/P	Chlorophyll a (µg/L)	Phaeophytin (µg/L)	Silicate (µg/L)	TSS (mg/L)
01	22.2	36.4	6.4	8.0	0.109	0.006	6.00	0.60	0.28	70.0	4.1
02	21.2	36.5	5.9	7.9	0.044	0.010	-	0.20	0.34	10.1	2.8
03	26.9	36.4	6.1	7.9	0.072	0.005	-	0.17	0.09	11.8	4.5
04	26.7	36.7	6.3	7.9	0.189	0.001	-	1.09	0.41	2.8	5.8
05	20.7	36.5	6.6	8.0	0.084	0.004	1.60	0.40	0.17	47.6	5.8
06	20.5	36.5	6.0	7.9	0.158	0.013	9.33	0.37	0.39	53.2	2.9
07	25.8	37.0	6.1	8.0	0.200	0.008	-	0.27	0.08	47.6	3.4
08	24.8	36.8	6.4	8.0	0.089	0.079	-	0.40	0.22	33.6	5.9
09	25.1	35.7	6.7		0.161	0.002	0.17	0.78	0.26	112.0	14.3
10	20.1	36.5	5.8	7.9	0.167	0.003	1.00	0.64	0.51	70.0	2.5
11	27.2	36.6	5.9	8.0	0.082	0.004	8.00	0.42	0.11	58.8	7.3
12	25.7	36.3	6.2	7.9	0.248	0.005	2.20	0.28	0.12	0.0	3.8
13	18.9	36.4	7.5	7.5	0.200	0.052	6.64	0.44	0.39	86.8	5.5
14	20.5	36.6	6.3	8.0	0.083	0.009	10.00	0.64	0.40	30.8	2.8
15	26.8	36.9	6.1	7.9	0.114	0.003	6.00	0.30	0.17	0.0	5.2
16	27.3	36.5	6.0	8.0	0.140	0.004	3.00	0.26	0.15	53.2	7.3
17	23.2	36.2	6.6	8.0	0.181	0.002	0.83	0.23	0.13	19.0	6.2
18	22.2	36.6	6.0	7.9	0.060	0.003	-	0.26	0.21	16.5	3.4
19	27.2	36.4	6.0	7.9	0.066	0.004	-	0.17	0.05	12.9	3.1
20	26.4	36.3	5.8	8.0	-	-	-	0.61	0.21	-	4.5
21	20.3	36.4	6.4	7.8	0.074	0.004	8.00	0.51	0.35	42.0	5.1
22	20.8	36.5	6.2	7.9	0.078	0.014	-	0.28	0.33	26.0	3.4
23	27.1	36.4	5.9	7.9	0.073	0.006	-	0.17	0.05	36.4	4.9
24	25.1	36.8	6.3	8.0	0.115	0.003	-	0.23	0.11	47.6	5.4
25	20.2	36.5	7.3	8.4	0.076	0.023	7.14	0.38	0.65	50.4	2.8
26	23.2	36.6	6.5	8.0	0.092	0.004	8.00	0.34	0.20	33.6	6.9
27	26.0	36.8	6.0	7.9	0.112	0.004	-	0.38	0.17	12.0	4.1
28	24.2	36.5	3.5	8.1	0.076	0.005	-	0.25	0.25	24.4	3.1
29	20.4	36.5	5.8	7.9	0.069	0.020	14.67	0.31	0.42	47.6	6.6
30	21.2	36.6	6.2	8.0	0.173	0.000	0.25	0.46	0.33	86.8	2.2
31	27.4	36.8	6.0	8.0	0.095	0.000	-	0.88	0.26	1.1	8.4
32	27.3	36.3	5.9	7.9	0.095	0.004	-	0.22	0.09	42.0	5.9
33	23.0	36.6	6.5	8.0	0.110	0.003	6.00	0.18	0.09	0.0	11.1
34	21.1	36.5	6.0	7.9	0.095	0.011	-	0.27	0.36	0.0	6.0

Station	Temp. °C	Salinity (psu)	DO (mg/L)	pH	DIN (mg/L)	DIP (mg/L)	N/P	Chlorophyll a (µg/L)	Phaeophytin (µg/L)	Silicate (µg/L)	TSS (mg/L)
35	25.5	36.2	6.3	7.9	0.069	0.004	-	0.24	0.10	0.0	4.8
36	27.1	36.3	4.1	8.1	-	-	-	0.23	0.08	-	2.5
37	21.2	36.5	7.2	10.4	0.076	0.002	1.25	0.27	0.22	0.0	3.2
38	20.8	36.5	6.1	7.9	0.084	0.018	10.00	0.27	0.29	0.0	3.9
39	26.0	36.4	6.1	7.9	0.067	0.003	-	0.18	0.07	0.0	5.5
40	25.8	36.4	6.1	7.9	0.123	0.003	7.00	0.57	0.18	0.0	6.4
41	19.7	36.4	7.4	8.9	0.142	0.000	-	0.37	0.23	28.0	3.7
42	22.3	36.6	6.6	8.0	0.054	0.007	-	0.42	0.29	61.6	2.9
43	26.4	37.0	6.0	7.9	0.111	0.008	-	0.29	0.08	4.8	6.1
44	26.9	36.2	5.8	8.0	0.188	0.008	-	0.37	0.12	11.2	6.7
45	22.7	36.7	6.4	8.0	0.102	0.005	-	0.51	0.28	86.8	6.1
46	24.2	36.7	6.4	8.0	0.110	0.003	-	0.10	0.04	70.0	2.2
47	27.0	36.9	6.2	8.0	0.141	0.006	-	0.66	0.27	21.8	5.2
48	27.1	36.3	5.9	8.0	0.207	0.005	-	0.17	0.07	12.0	5.6
49	20.9	36.5	6.8	5.8	0.080	0.009	-	0.40	0.24	0.0	3.4
50	27.0	36.4	5.9	7.9	0.066	0.005	6.00	0.41	0.13	25.2	3.6

Appendix D. Summary by station of mean ERM quotients and the number of contaminants that exceeded corresponding ERL or ERM values (from Long et al. 1995) for 50 South Florida coastal ocean sites sampled May 2007.

Station	# of ERLs Exceeded	# of ERMs Exceeded	Mean ERM-Q
01	0	0	0.009
02	1	0	0.015
03	1	0	0.014
04	0	0	0.004
05	1	0	0.016
06	0	0	0.006
07	0	0	0.007
08	0	0	0.010
09	0	0	0.003
10	0	0	0.006
11	1	0	0.017
12	0	0	0.012
13	1	0	0.021
14	0	0	0.007
15	0	0	0.006
16	0	0	0.006
17	0	0	0.004
18	0	0	0.007
19	0	0	0.005
20	0	0	0.008
21	0	0	0.008
22	0	0	0.007
23	0	0	0.007
24	0	0	0.009
25	0	0	0.009
26	0	0	0.007
27	0	0	0.012
28	1	0	0.016
29	1	0	0.015
30	0	0	0.009
31	0	0	0.007
32	1	0	0.013
33	1	0	0.017
34	1	0	0.013
35	0	0	0.009
36	1	0	0.018
37	1	0	0.016
38	1	0	0.016
39	1	0	0.015
40	1	0	0.011
41	1	0	0.014
42	0	0	0.007
43	0	0	0.010
44	0	0	0.007
45	1	0	0.019
46	0	0	0.007
47	0	0	0.013
48	0	0	0.009
49	1	0	0.016
50	1	0	0.016

Appendix E. Summary by station of benthic macroinfauna characteristics from 50 South Florida coastal ocean sites (2 replicate 0.04-m^2 grabs per site). H′ derived using base 2 logarithms. (*values within lower 10th percentile of a specific benthic variable)

Station	Mean # Taxa per Grab	Total # Taxa	Mean Density (#/m^2)	Mean H′ per Grab
01	42.5	67	5325	5.03
02	53	88	3637.5	5.25
03	29	43	1600	4.89
04	42.5	72	5400	4.89
05	63	104	6962.5	5.55
06	57.5	86	4062.5	5.96
07	45	68	4475	5.08
08	54.5	84	5837.5	5.43
09	44	64	4100	5.39
10	42.5	65	3287.5	5.15
11	19.5	31*	1587.5	4.26*
12	43.5	67	4275	5.10
13	39	64	2512.5	5.48
14	39	61	3862.5	5.30
15	42	67	3500	5.42
16	56.5	84	8812.5	6.92
17	41	65	3537.5	4.80
18	44.5	76	2550	5.38
19	15.5*	25*	1250*	3.36*
20	18.5*	31*	1325	3.50*
21	45.5	64	8487.5	6.06
22	67.5	101	4350	6.14
23	86	122	10912.5	6.33
24	32	52	1075*	4.98
25	68.5	110	6175	6.09
26	43	69	3750	5.24
27	57.5	85	7787.5	5.55
28	27.5	46	1662.5	4.67
29	47	79	2937.5	5.51
30	30	50	1950	4.88
31	16.5*	27*	1425	4.09*
32	31	50	2412.5	4.86
33	45.5	74	8050	4.39*
34	57	85	5150	5.85

Station	Mean # Taxa per Grab	Total # Taxa	Mean Density (#/m^2)	Mean H′ per Grab
35	48.5	81	4862.5	5.65
36	48.5	81	3625	5.53
37	37.5	61	9550	6.62
38	55.5	86	4187.5	5.70
39	14.5*	21*	1075*	4.72
40	44.5	75	7125	4.59
41	74.5	117	8587.5	6.60
42	57.5	87	3837.5	5.84
43	30	50	1412.5	5.05
44	40.5	65	3000	5.25
45	53.5	87	3087.5	5.53
46	25.5	41	1200*	4.77
47	16*	29*	662.5*	4.33*
48	35.5	61	2575	5.06
49	44.5	73	4387.5	5.38
50	60	94	4837.5	5.66

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